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The evolution of the cavitation bubble driven by different sound pressure

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Abstract

In this paper, the relation between the ambient radius R_0 of the acoustic cavitation bubble and its driving pressure was investigated by an improved method. The evolution of the bubble was gained with a long-distance microscope and a bundle of 532 nm laser switched by an acousto-optic modulator. The ambient radius R_0 was determined by fitting the numerical calculation based on Rayleigh–Plesset equation to the experimental data. The results showed that as the sound pressure increased R_0 decreased at beginning and increased after the pressure reached to about 1.2 atm. Although the same rule was gotten from the relation between the maximum radius R_m and the sound pressure, the ratio R_m/R_0 varied monotonously with the sound pressure. It indicates that enhancing the sound pressure can increase the compression ratio of the bubble even if the mass inside the bubble is also increased.

Keywords: Cavitation; Radius; Sound pressure

1. Introduction

As ultrasound propagates through liquid, driving by the acoustic pressure, the tiny bubbles in liquid oscillate and grow to be visible to the naked eyes. This phenomenon is termed the acoustic cavitation in which a number of physical and chemical effects take place, such as chemical reactions, erosion, sonoluminescence (SL) [1], and so on. Large energy focusing at collapse leads to ultrahigh temperature and pressure inside the cavitation bubble. It is so high that the cavitation bubble can emit light, i.e. SL, and even can be used for sono-fusion [2], during the violent collapse. Since Gaitan [3] firstly realized the stable SL from a single gas bubble by means of degassing water in 1990s, the stability of the single bubble makes the dynamical measurement of the bubble possible. Generally, there are two approaches to investigate the characters of the bubble dynamics experimentally. One is Mie scattering, and the other is stroboscopic microphotographics. Mie scattering is a mature technique with high-speed response of nanoseconds, but it can only get relative value of the bubble's size or radius for a spherical bubble, and has a strong dependency on the scattering angle [4,5]. Tian et al. [6] captured a moving image of the bubble with their stroboscopic imaging system by the beat frequency method that means the phase between the driving sound and the illuminating light pulse kept slowly shifting due to a fixed frequency difference between them. In our experiment, the stably levitated bubble was illuminated by a narrow laser pulse whose phase could be shifted digitally and a sequence of images of the bubble were recorded by a video camera through a long distance microscope. The evolution of the bubble was gained by the extraction of bubble size from the image with computer. The ambient radius R_0 was obtained by fitting the numerical calculation based on Rayleigh–Plesset equation to the experimental data.

2. Lock-in integral imaging technique

The experimental resonator used was a spherical 100 ml flask on whose equator a pair of piezoelectric transducers

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(PZT) was cemented with epoxy symmetrically. An ultrasonic signal was generated by an arbitrary waveform generator (Agilent 33250A) at a fixed frequency of 25 kHz, near the eigenfrequency of the resonator, boosted by an amplifier (Brüel & Kjær2713), and connected to the transducers via an impedance matching network. A needle hydrophone (NTR Systems Inc., TNU001A) was plugged into the cell to get the acoustic pressure. The bubble levitated at the antinode of the pressure was imaged by a long-distance microscope (Hirox KH-3000) which can amplify an object 6.50 cm away from its object lens by 400 times in maximum. A quartz window was opened on the surface of the flask to observe the bubble. The illuminating system contained three parts: a 532 nm Nd YAG laser, an acousto-optic modulator (AA sa AA.MT.350) whose carrier frequency was 350 MHz, and a digital delay/pulse generator (SRS DG535). Additionally, a photo-multiplier tube (PMT, Hamamatsu R212) was used to detect the light of sonoluminescence. The experimental arrangement is shown in Fig. 1.

Triggered by a synchronous TTL signal from the signal generator (33250 A), the DG535 generated a given pulse to drive the acousto-optic modulator after a given delay. Both duration and delay could be digitally changed. The acousto-optic modulator was used to switch laser beam and the laser beam through the acousto-optic modulator became the pulse whose duration and phase were adjustable digitally. Because the light pulse shared the same frequency with the driving sound, the obtained image of the bubble under the shining of the laser pulse was locked in a given phase although the bubble oscillated continuously. Shifting the delay time of the light pulse, a sequence of the bubble images in one cycle could be acquired. In the previous stroboscope imaging systems [6], a frequency difference between the driving sound and the trigger signal was used to realize the continuous phase-shift, so that the illuminating light pulse was not flashed at a fixed phase, but moved slowly, during the integral exposal duration. In our system, however, the phase was locked in the exposal duration. As a result, the time resolution of the picture has been improved to twice, because there was no slow moving duration, the same as the exposal duration usually. For example, if the exposal duration was 100 ns, the actual time resolution would be one image per 200 ns in the beat frequency stroboscope system, and be only 100 ns in our system. Furthermore this method adopted a digital phase-shift technique that was essentially different from the pace-locked imaging of the beat frequency method. The phase-shift could be digitally controlled by programming through GPIB and the pace of each shift could be different. The pace at slowly changed phase of bubble shape could be lengthened to save time and the pace at fast-changed phase, especially near the collapse, could be shortened to enhance the precision. Especially illuminated by the shorter light pulse, the variable pace could not only save the experimental time in slowly changing part of the bubble evolution curve, but also keep the precision in faster changing part. In present experiment, the sound period was 40 μs and the width of the light pulse was 100 ns which could be reduced to the minimum of 20 ns, the pace for each frame and the time resolution were 100 ns too; the time of exposure was 1/30 s for the video camera. So each frame was integrated about 833 cycles for a fixed phase. 400 pictures were acquired for one whole cycle for about 13 s. The space resolution of the microscope was 0.23 μm/pixel. The picture obtained was the shadow of bubble (see the inset in Fig. 2). In order to measure the radius of the bubble efficiently, we wrote a measuring code that identified the boundary of the bubble shadow, took count of the pixels inside the bubble boundary, and transformed the number of pixels to the radius assuming the bubble is in sphere. In our experiment, the bubble always kept the shape in sphere quite well so that we had neglected the distortion of the bubble in the measuring code. Occasionally, we got some abnormal pictures in which the bubble shape was significant deformation from the circle. We found the deformation was caused by the spherical bubble's moving during the exposal interval, instead of its deformation from the sphere. The bubble's moving, of course, would lead to the measuring errors.

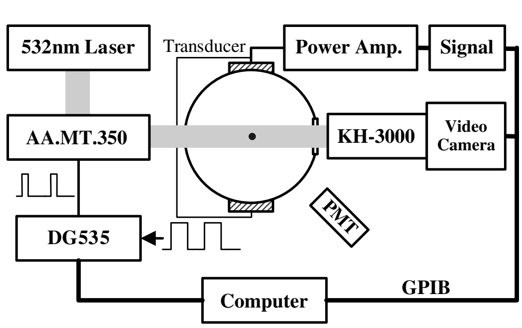

Fig. 1. Sketch of the experimental setup.

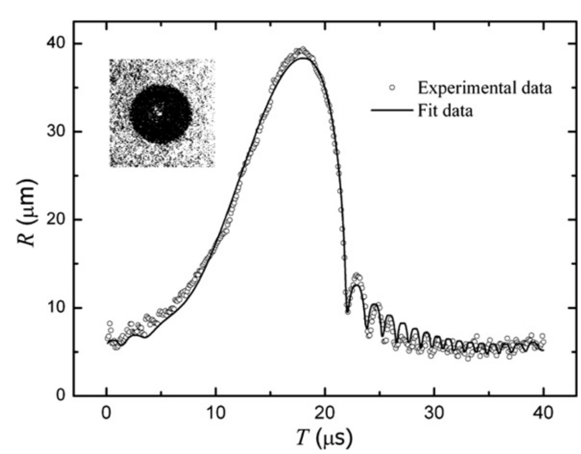

Fig. 2. Bubble's radius evolution curve. The inset is the shadow picture of bubble.