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Memory effect and redistribution of cavitation nuclei in a thin liquid layer

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ABSTRACT

Temporal evolution and spatial distribution of acoustic cavitation structures in a thin liquid layer were investigated experimentally with high-speed photography. The inception and disappearance processes of cavitation bubble cloud revealed that the metastable cavitaton structures formed in the thin liquid layer caused a long-term "memory effect". A factor which weakens the memory effect was identified. The distribution of cavitation nuclei was investigated by changing the temporal decay of the memory effect.

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1. Introduction

After cavitation bubbles collapse, remnants of cavitation bubbles (nuclei) persist in the original location and act as seeds for subsequent cavitation events. We call this physical process "memory effect". The investigation on memory effect will help us understand the relationship of cavitation bubble cluster and cavitation nuclei, and will contribute to the application of cavitation in ultrasonic sonochemistry, ultrasonic cleaning and ultrasonic medical treatment [1].

Because there are cavitation nuclei (stabilized or unstabilized) in the liquid, cavitation can occur at lower acoustic pressure than the tensile pressure of liquid [2–4]. Harvey [5] (1944), Fox [6] (1954) have noticed that the nuclei (unstabilized) may form as fragments of bubbles that persist from collapse of transient cavities. Flynn [7] (1984), Henglei [8] (1986), Fowlkes [9] (1988) have discussed the process of above-mentioned unstabilized nuclei becoming new cavitation bubbles. In addition, Yavas [10] (1994) investigated the enhancement of acoustic cavitation at a liquid–solid interface fol1owing laser-induced bubble formation. Their experimental results indicate that metastable ultramicroscopic bubbles formed on the solid surface cause a long-term "memory effect" on acoustic cavitation. Bai [11] (2009) observed the ejection process of micro-bubbles from the top of a cavitation bubble which is located in a pit structure by means of high-speed photography. They give an explanation of why the pit structures act as a source of nuclei. Wang [12] (2012) investigated the spatial distribution of the cavitation bubbles in response to each histotripsy pulse. Then found that cavitation memory may have distinct influence on the lesion development process in histotripsy.

On the basis of the above research, this study investigated the memory effect and redistribution of cavitation nuclei in a thin liquid layer (between two parallel solid walls). The two-dimensional nature of thin liquid layer brings about some new characteristics to bubbles and nuclei. To our knowledge, there has not been any study on the cavitation memory effect in a very thin liquid layer.

2. Experiment

The experimental setup consisted of the ultrasonic cavitation devices, the high-speed imaging and illumination system, fixing and adjusting devices, hydrophone and oscilloscope, etc (as shown in Fig. 1(a)) (the experimental setup photo see also Bai [13] (2014)). The ultrasonic horn was submerged in water in a transparent chamber (600 mm × 330 mm × 330 mm). Fresh tap water is used in the experiment. The impurities or dissolved gas in tap water will reduce the threshold at which cavitation appears. The similar results can be obtained in deionized water but with less cavitation bubbles as compared to in tap water. The water temperature in the experiments is about 20 °C. Cavitation structure is recorded with a high-speed camera (Photron Fastcam SA-1, Photron Ltd., Japan), and is illuminated with high-brightness light sources.

Fixing and adjusting devices are used to fix the transducer and adjust the distance between the radiating surface (diameter:

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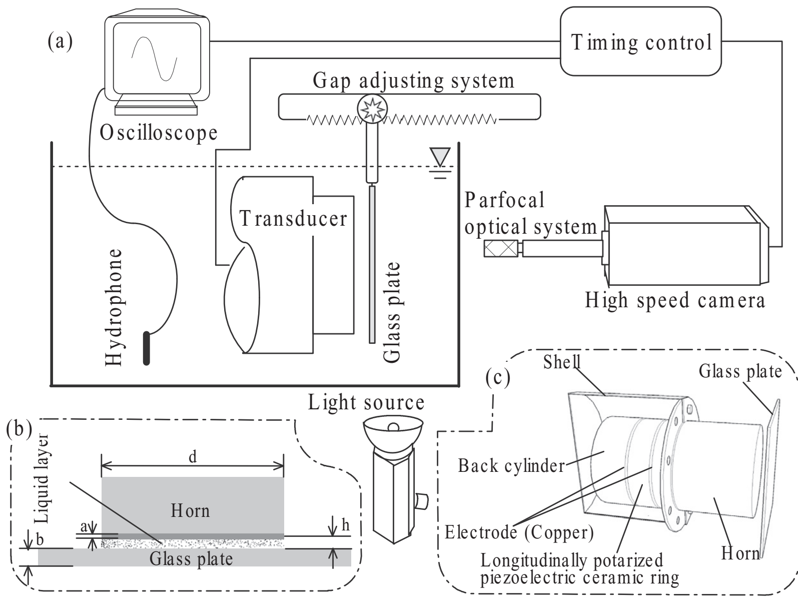

Fig. 1. (a) Experimental setup; (b) Thin liquid layer between horn and glass plate; (c) Piezoceramic sandwich transducer.

d = 30 mm) and reflection plane (glass plate thickness: b = 5 mm) in the experiment (as shown in Fig. 1(b)). The piezoceramic sandwich transducer (frequency: 40 kHz) is a continuous work in the power-type transducer (140–160w in our experiment, exclude the power loss due to voltage conversion). The transducer is well enveloped and can be submerged in water completely (as shown in Fig. 1(c)).

3. Results

The cavitation structures vary for different liquid layer thickness in the experiment (as shown in the Fig. 2). When gap distance is 8.6 mm, smoker cavitation structures are formed [14]. The cavitation bubble cluster will link to one another with the decrease of gap distance. The non-cavitation areas will be surrounded by cavitation bubble clusters. Under the effect of cluster surface tension, the cavitation structure shows circular pattern (as shown the subfigures τ = 2.416 s, τ = 3.008 s in the Fig. 2). The formation mechanism of cavitation structures in thin liquid layers will be described by the current authors in another paper in the near future. Layer thickness = 1.01 mm was selected in our experiment to investigate the memory effect, because there is much position information for the circular pattern: the cavitation area and non-cavitation area intertwine with clear boundaries (as shown in the Fig. 3(b)). The position information will contribute to a more accurate evaluation of cavitation memory effect. There are no cavitation bubbles in the liquid of circular areas (as shown the dark areas in the Fig. 3(b)). The circular pattern remains stable in dozens of millisecond. The

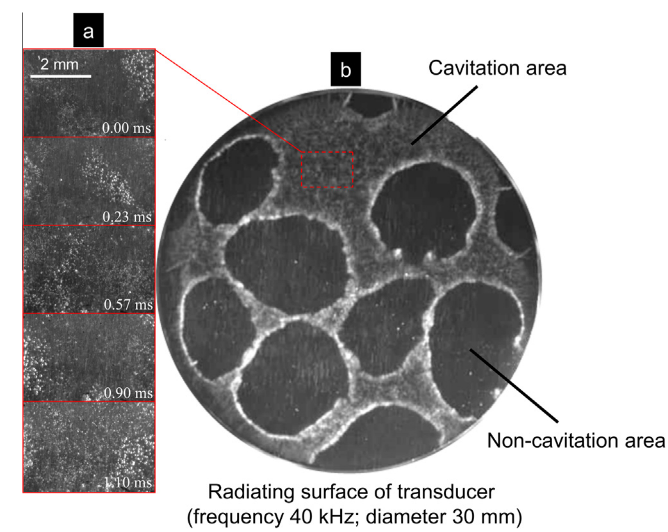

Fig. 3. Cavitation structure in thin liquid layer. (a) Cavitation cluster; (b) Snapshot of cavitation pattern.

memory effect of the cavitation structure was investigated in the same condition as in Fig. 3.

The memory effect of cavitation structure was achieved by repeated turn-on and turn-off of transducer (as shown in the Fig. 4). The circular pattern of cavitation bubble cloud changed greatly with time (t = 0 ms, 100 ms, 200 ms, 300 ms). After turning

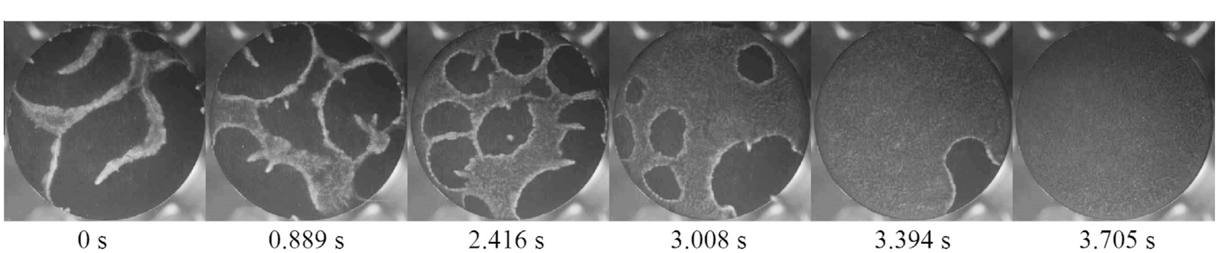

Fig. 2. The evolution of cavitation structures in a thin liquid layer when the gap distance vary from 8.6 mm to dozens of microns driven by stepmotor.

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