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Evaluation of bubble cloud cavitation in multi-frequency ultrasonic wave irradiation

複数超音波の同時照射による気泡クラウドキャビテーションの評価

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1. Introduction

In order to improve the efficiency of sonoporation, several methods based on micro bubble manipulation have been proposed [1, 2]. In these methods, bubble cloud formation by irradiation of ultrasonic trapping wave followed by bubble cloud cavitation by irradiation of high intensity ultrasonic wave is a key technology in improvement of micro hollow production on the flow channel wall. However, bubble cloud cavitation shows complicated mechanisms and the optimization of the ultrasonic wave irradiation sequence becomes difficult tasks. For example, bubble clouds move in the vicinity of the wall during high intensity ultrasonic wave irradiation and they tend to move from the wall in tens of microseconds. Because the efficiency of micro hollow production increases when the bubbles are destructed in the vicinity of the wall, it might be necessary to hold the bubble clouds in the optimal position during high intensity ultrasonic wave irradiation.

Micro bubble cloud shows different dynamics depending on the frequency of the ultrasonic wave. Bubble clouds's size and the separation between the neighboring bubble clouds, and the time to form the bubble clouds change for different frequency of ultrasonic wave. Moreover, various dynamics, such as fragmentation to small bubble clouds and generation of the resonance bubbles are often observed.

In this paper, first, we evaluate the bubble cloud cavitation for different frequency of ultrasonic wave. Simultaneous observation of high speed camera for observation of bubble cloud dynamics and micro hollow observation by confocal laser microscope are adopted in this evaluation. Then, a novel ultrasonic wave irradiation sequence which uses two ultrasonic waves with different frequencies is proposed.

2. Methods

Fig.1 shows the experimental set-up. Micro bubbles (Levovist, Bayer Helthcare, Germany) are introduced into the flow channel made by NIPA gel. Two concave ultrasonic transducers with different frequency of 2.5 MHz and 1.0 MHz are used for irradiating multi-frequency ultrasonic waves. They are focused at the flow channel. In the experiment, first, an ultrasonic wave (Trapping ultrasonic wave) irradiate from 2.5 MHz transducer. Sound pressure of the wave is smaller than the threshold value of bubble destruction (100kPa). Micro bubbles receive an acoustic radiation force (the Bjerknes force) and they aggregate and make bubble clouds. The bubble clouds are attached to the upper part of flow channel by the primary Bjerknes force. Then, high intensity ultrasound wave irradiates for destructing the bubble clouds. The bubble cloud dynamics in bubble cloud cavitation is observed by high speed video camera (Phantom V711, Vision research, NJ. USA).

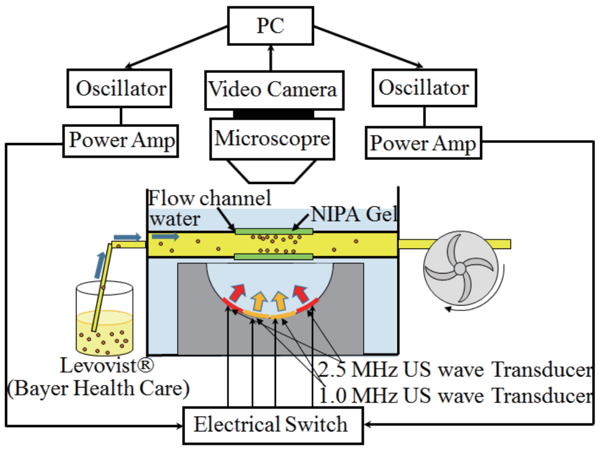

Fig. 1 Experimental set-up

3. Results

First, we evaluate the micro hollows produced on the flow channel wall for different frequency of the ultrasonic wave. Frequencies of 1MHz, 2.5MHz and 7.5 MHz are tested. Sound pressure of the ultrasonic waves is set to 1 MPa. Among them, frequency of 2.5 MHz is the frequency nearest to the resonance frequency of micro bubbles. Efficiency of micro hollow production for 7.5 MHz is lower than that for 2.5

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MHz, and a small amount of micro hollows are produced for 1 MHz which is shown in Fig.2. However, for 1 MHz, we observed interesting phenomena. That is, the bubble clouds make large bubble cloud, and then, they generate large single bubble as well as production of fragmented many small bubbles. This result implies that ultrasonic wave of frequency of 1 MHz has an effect of changing dynamics of bubble clouds rather than the destruction of bubbles themselves.

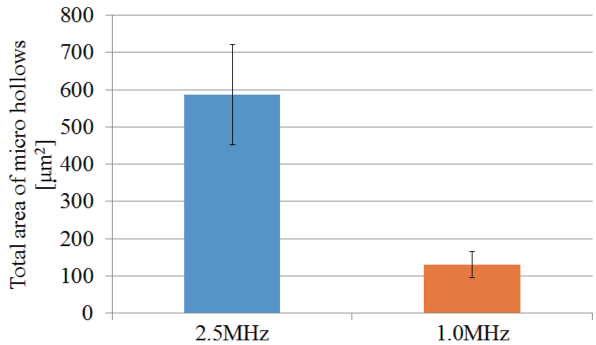

Fig. 2 Total area of micro hollows when high intensity US waves of 2.5 MHz and 1.0 MHz irradiate.

Next, the bubble cloud dynamics in 1.0 MHz and 2.5 MHz simultaneous irradiation is observed by high speed video camera. Fig.3 shows the result. Each photograph in Fig. 3 shows bubble clouds at different time during bubble cloud cavitation. Left row shows the result for 2.5MHz ultrasonic wave irradiation (Sound pressure: 1 MPa) and right row shows the result of simultaneous irradiation of 2.5 MHz (Sound pressure: 1 MPa) and 1.0 MHz (sound pressure: 700 kPa). If 2.5 MHz ultrasonic wave irradiates, bubble clouds disappears with time due to bubble cloud cavitation. But when two frequency ultrasonic waves irradiate, the relative size of bubble cloud increases, and they tend to keep their positions without destructing compared with the result for 2.5 MHz. This result shows that the duration time to hold the positions near the wall can be prolonged by adding 1 MHz ultrasonic wave. This result is consistent with the result observed when 1 MHz ultrasonic wave irradiates.

Fig. 5 shows the efficiencies of micro hollow production for different ultrasonic wave irradiation sequence. Experiments are carried out three times and mean and the standard deviation are shown in the figure. We found that the total area of micro hollows in simultaneous irradiation (Sound pressure of 1MHz ultrasonic wave: 700 kPa) is about 3 times higher than that of 2.5 MHz single ultrasonic wave irradiation. This result shows that 2.5 MHz and 1.0 MHz simultaneous irradiation sequence is effective in bubble cloud cavitation.

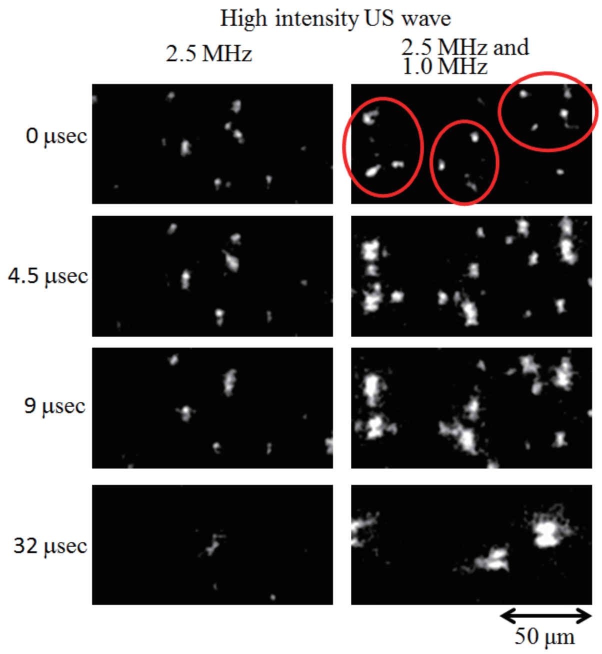

Fig. 3 Bubble clouds when high intensity US wave with two frequencies of 1.0 MHz and 2.5 MHz irradiates.

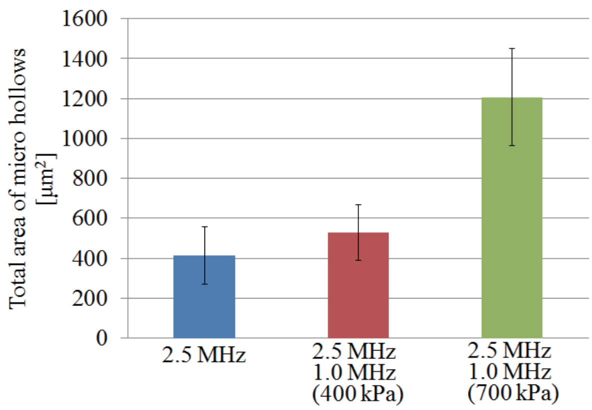

Fig. 5 Total area of micro hollows in high intensity US wave irradiation with 2.5 MHz single, 2.5 MHz + 1.0 MHz (400 kPa), and 2.5 MHz + 1.0 MHz (700 kPa), respectively.

4. Conclusion

We demonstrated the efficiency of bubble cavitation sequence using 1.0 MHz ultrasonic wave simultaneous irradiation was effective in improvement of the efficiency of micro hollow production in bubble cloud cavitation.

Acknowledgment

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