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Numerical Study of Single Bubble Dynamics in Megasonic Field for New Physical Cleaning Method

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Cavitation in megasonic field is the useful technique in the wafer cleaning. However, the physical forces of cavitation bubble collapse induced by megasonic field can induce pattern damage. Therefore, the efficient physical wafer cleaning method without pattern damage is desired [1].

The clarification of mechanism and the control of megasonic cleaning are necessary for megasonic cleaning without pattern damage. Although the collapse of cavitation bubble generated by megasonic field, the acoustic streaming and the chemical effect are thought to influence on megasonic cleaning [2, 3], the detailed mechanism of megasonic cleaning is not yet clarified.

Many experimental researches have been performed about megasonic cleaning, e.g. the analyses of particle removal and pattern damage [4] and the observation of bubble behavior [5]. However, in experiment, it is difficult to measure the physical forces and analyze the high speed bubble behavior. It is thought that numerical study overcomes the difficulties. Therefore, in the present study, the bubble behavior in a megasonic field is analyzed to clarify the mechanism of a megasonic cleaning.

Single bubble dynamics in a megasonic field is analyzed as the first step of the numerical study about megasonic cleaning. A locally homogeneous model of a gas-liquid two-phase medium [6, 7] is applied to the calculation of single bubble. The model is suitable for the simulation of the complex bubble, the propagation of a pressure wave and bubble-bubble interaction. The axisymmetric calculation of the single bubble in the standing wave of a megasonic field between oscillating wall and water surface is performed in the present study. The distance between oscillating wall and water surface is 1.5 mm, and the megasonic frequency is 1 MHz. The bubble initial position is 0.9 mm from the wall.

Figure 1 shows the time evolution of the pressure distribution and iso-surface of void fraction of 0.5 in the calculation of initial bubble radius R_0 = 3 μm. The upper and lower figures show the calculation whole area and the area near the bubble, respectively. The bubble grows until the time of Fig. 1(ii) when the ambient pressure is maximum, and the bubble shrinks at the time of Fig. 1(iv) when the ambient pressure is minimum. The internal pressure of the bubble becomes high at the time of Fig. 1(iv) and rebounds. The bubble repeats the cycle of Fig. 1. Figure 2 shows the time histories of bubble position from the wall. In the present calculation condition, the antinode of the standing wave is above the bubble and the node is below the bubble, and the resonant bubble radius is about 2.8 μm. Therefore, it is found that the bubble of R_0 smaller than the resonant radius (R_0 = 2 μm) moves to the antinode and the bubbles of R_0 larger than the resonant radius (R_0 = 3 and 5 μm) moves to the node. Figure 3 shows the time histories of the radius and the ambient pressure of the bubble of R_0 = 2 μm. The bubble of R_0 = 2 μm is found to be in-phase oscillation against the pressure fluctuation. When the bubble is small, the ambient pressure is high and the force due to the ambient pressure gradient toward the node acts on the bubble. On the other hand, when the bubble is large, the force toward the antinode acts on the bubble. The net force acting the bubble during the one cycle of the pressure fluctuation is found to be direction of the antinode. This is the primary Bjerknes force. The present result corresponds to the conventional experiment results. The present numerical simulation is easy to be applied to the nonspherical bubble analysis near wall, and the results contribute to the development of new physical megasonic cleaning method.

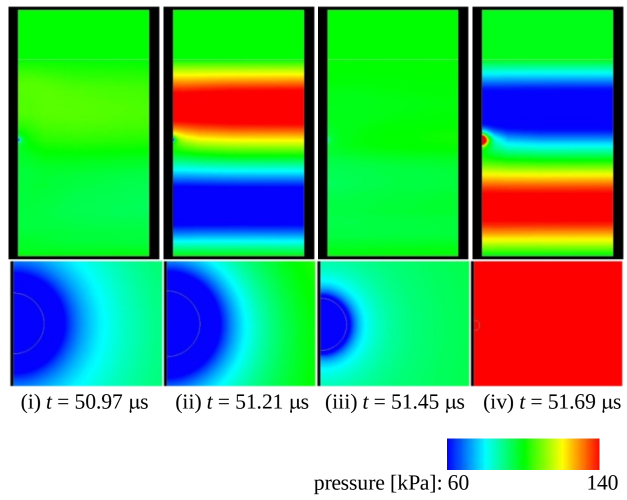

Fig. 1 Time evolution of pressure distribution and iso-surface of void fraction of 0.5 (upper: calculation whole area, lower: near bubble area, R_0 = 3 μm)

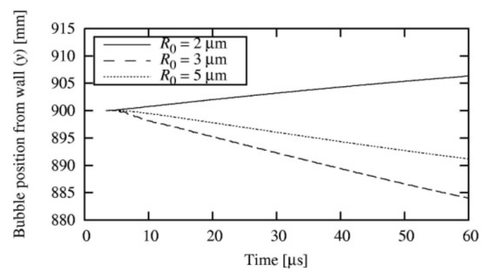

Fig. 2 Time history of bubble position

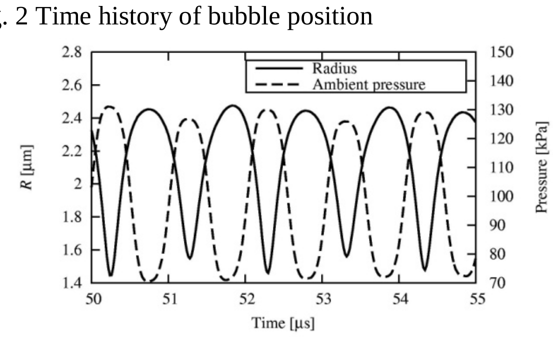

Fig. 3 Time histories of bubble radius and ambient pressure (R_0 = 2 μm)

References

1. J. Ishimoto et al., Solid State Phenomenon, **187**, pp. 145-148.
2. R. Kohli and K. L. Mittal, Developments in Surface Contamination and Cleaning Vol. 3, Elsevier (2011).
3. W. Kim et al., Appl. Phys. Lett., **94** (2009), 081908.
4. B.-K. Kang et al., Solid State Phenomenon, **195** (2013), pp. 169-172.
5. W. Kim et al., Ultrasonics, **50** (2010), pp. 798-802.
6. N. Ochiai et al., J. Fluid Sci. Tech., **5**(3) (2010), pp. 416-431.
7. K. Okuda and T. Ikohagi, Trans. JSME Ser. B, **62**(603) (1996), pp. 3792-3797 (in Japanese).