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Generation and Reduction of Ultrafine Bubble by Ultrasonic Irradiation
超音波照射によるウルトラファインバブルの生成と消滅

Yoshiyuki Asakura[1†], Hodaka Matsushima[2], and Keiji Yasuda[2]
([1]Honda Electronics.; [2]Grad. School Eng., Nagoya Univ.)
朝倉　義幸 [1†], 松島　穂高 [2], 安田　啓司 [2] ([1] 本多電子, [2] 名大院工)

1. Introduction

Bubbles of less than 1 μm in diameter are called ultrafine bubbles. Ultrafine bubbles are often generated by pressurized dissolution method and their average diameter is around 100 nm. Since buoyancy of ultrafine bubbles in water is quite small, ultrafine bubbles have very long life. Ultrafine bubble water attracts attention in the field of cleaning[1)], agriculture[2)], fisheries, and drug delivery system[3)].

On the other hand, ultrasound in liquid have a close relation to bubbles. For example, cavitation bubbles remove dirt in ultrasonic cleaner and microbubbles are used as a contrast medium in ultrasonic diagnosis. When high intensity ultrasound is irradiated in water, cavitation bubbles are generated from bubble nucleus. The diameter of cavitation bubbles is of the order micrometers. Since it is though that diameter of bubble nucleus in pure water is smaller than 100 nm, it is possible that ultrafine bubbles are generated during bubble growth from nucleus to cavitation.

In this study, ultrasound was irradiated to ultrapure water and water containing high-concentration ultrafine bubbles. The change of number density of ultrafine bubbles with irradiation time was investigated in various ultrasonic frequency and power.

2. Experiment

The experimental setup is shown in **Fig. 1**. To circulate cooling water, a vessel had double layer structure. The inside diameter of vessel was 56 mm. The vessel and vibration plates with a transducer were made from SUS304 stainless steel. Transducers were driven by a power amplifier which amplified a continuous sinusoidal wave produced by a signal generator. An effective electric power applied to transducers was calculated from a voltage at both ends of the transducers and a current measured by an oscilloscope and a current probe, respectively, and was constantly controlled by a control system. Transducers attached to the vessel were a Langevin multi-frequency transducer 45 mm in diameter at the frequency of 22, 43, and 128 kHz, and disk transducers 50 mm in diameter at 488 kHz and 1 MHz (Honda Electronics).

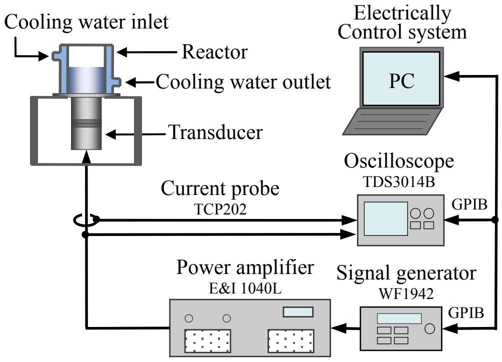

Fig. 1　Experimental setup.

Ultrapure water and ultrafine bubble water were used as samples. Ultrapure water was produced using systems equipped with both Elix-UV20 and Milli-Q Advantage for laboratory use (Millipore). Ultrafine bubble was generated by pressurized dissolution method (ultrafineGaLF, IDEC). Sample volume and temperature were 100 mL and 298 ± 0.1 K. The ultrasonic power that is, the energy applied to the sample per unit time was obtained by calorimetry. The number density of the ultrafine bubbles in the diameter range from 30 nm to 1000 nm was measured by nanoparticle tracking analysis method (NanoSight, Malvern).

3. Results and discussion

Ultrasound at 22 kHz was irradiated to ultrapure water and ultrasonic power was changed from 5 to 20 W. **Fig. 2** shows change of number density of ultrafine bubbles with ultrasonic irradiation time. The number density of ultrafine bubbles exponentially increases with time. This result proves that ultrasonic irradiation to water generates ultrafine bubbles. The number density of ultrafine bubbles becomes higher as ultrasonic power increases.

Ultrasound at 20 W was irradiated to ultrapure water and ultrasonic frequency was changed from 22 kHz to 1 MHz. Frequency

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yoshi@honda-el.co.jp

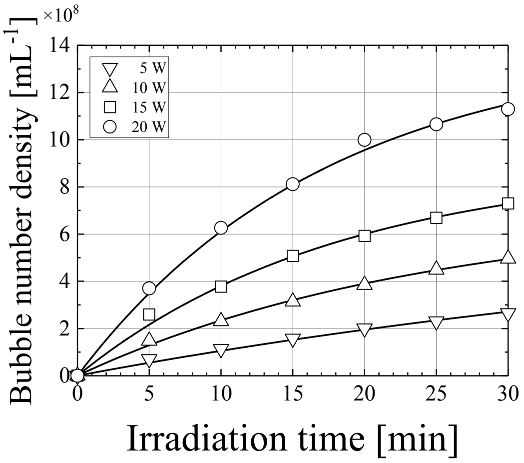

Fig. 2 Change of number density of ultrafine bubbles in ultrapure water with ultrasonic irradiation time at 22 kHz.

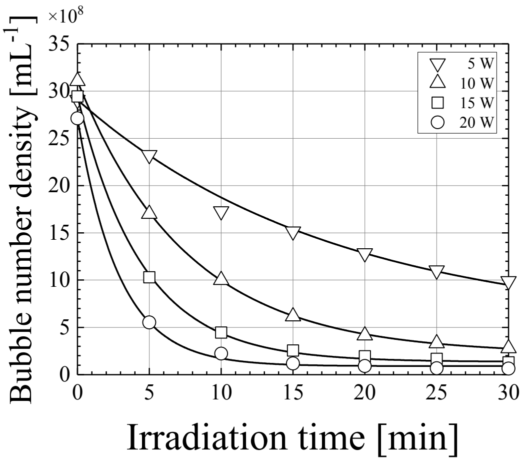

Fig. 4 Change of number density of ultrafine bubbles in ultrafine bubble water with ultrasonic irradiation time at 1 MHz.

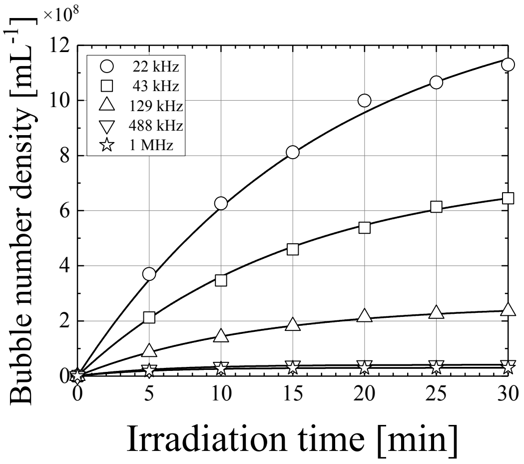

Fig. 3 Frequency dependence of number density of ultrafine bubbles in ultrapure water at 20 W.

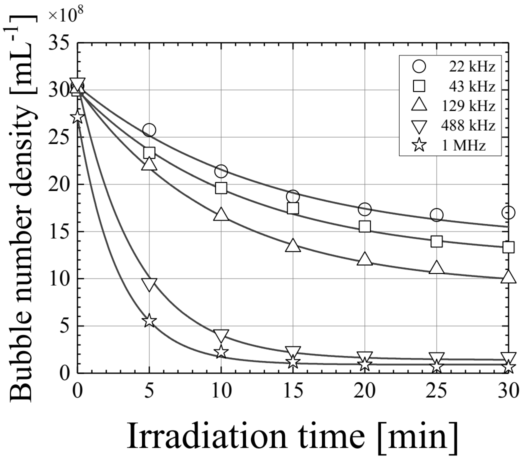

Fig. 5 Frequency dependence of number density of ultrafine bubbles in ultrafine bubble water at 20 W.

dependence of number density of ultrafine bubbles is shown in **Fig. 3**. The number density of ultrafine bubbles increases with decreasing frequency. The diameters of ultrafine bubbles after ultrasonic irradiation were 20 - 400 nm and the mode diameter of ultrafine bubbles was about 100 nm. The effects of ultrasonic frequency and power on the mode diameter of ultrafine bubbles were small.

Ultrasound at 1 MHz was irradiated to ultrafine bubble water and ultrasonic power was changed from 5 to 20 W. **Fig. 4** shows the change of number density of ultrafine bubbles with irradiation time. The number density of ultrafine bubbles decreases exponentially with time. The number density of ultrafine bubbles becomes lower as ultrasonic power increases.

Frequency dependence of number density of ultrafine bubbles in ultrafine bubble water at 20 W is shown in **Fig. 5**. The number density of ultrafine bubbles decreases with increasing frequency.

Therefore, it is clear that generation and reduction of ultrafine bubbles occur simultaneously by ultrasonic irradiation to water. It is thought that ultrafine bubbles generate from bubble nucleus and at the same time ultrafine bubbles grow to cavitation bubbles by expansion and contraction under ultrasonic irradiation. Since the cycle of expansion and contraction of bubbles becomes shorter as frequency becomes higher, ultrafine bubbles grow quickly and their number decreases.

References

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