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Visualization of ultrasound fields inside a protuberance of water generated by an ultrasonic atomizer
超音波霧化装置が生じる水面隆起内部音場のフォーカスト
シャドウグラフ法による可視化

Takeshi Aikawa[1†] and Nobuki Kudo[2] ([1]Graduate School of Information Science and Technology, Hokkaido Univ.; [2]Faculty of Information Science and Technology, Hokkaido Univ.)
相川　武司 [1†], 工藤　信樹 [2] ([1] 北海道大学　大学院情報科学院, [2] 北海道大学　大学院情報科学研究院)

1. Introduction

In fundamental studies on biological effects of ultrasound, a petri dish is frequently used as an exposure chamber, and cells cultured on the dish are irradiated by ultrasound generated by a transducer placed beneath the bottom of the dish. In many cases, ultrasound that can induce biological effects disturbs the surface of the culture medium inside the dish by radiation force, and reflection of the ultrasound at the disturbed surface makes a complex and unstable standing wave field inside the dish. Therefore, it is difficult to estimate the ultrasound dose at which cells were actually irradiated. In our previous study, a water container mimicking unduration of the water surface was develped using polyolefin resin foam, and ultrasound fields generated inside the container were visualized [1]. Resin foam was used because its characteristic acostic impedance is sufficiently lower than that of water; however, the boundary condition between water and the foam is different from that between water and air because there is almost no deformation of the foam. The purpose of the present study was to visualize ultrasound fields generated inside a water protuberance of an atomizer using a focused shadowgraphy technique [2,3].

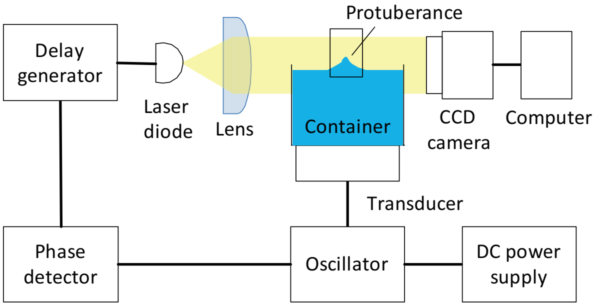

Fig. 1. A focused shadowgraphy system.

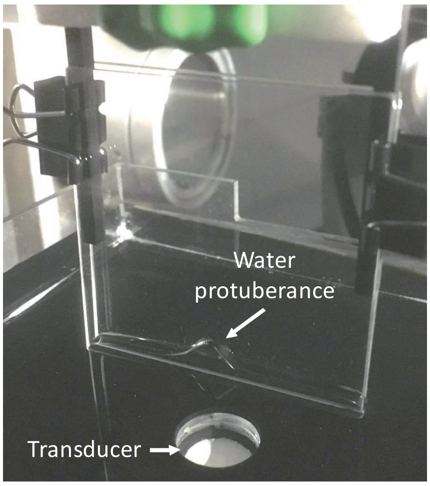

Fig. 2. Setup for observation of ultrasound fields inside a water protuberance.

2. Materials and methods

Fig. 1 shows the focused shadowgraph system used in this study. Short pulsed light (wavelength: 850 nm, pulse width: 5 ns, peak optical power: 1 W) emitted by a laser diode is collimated by a convex lens to illuminate an ultrasound field from a direction perpendicular to that of the ultrasound propagation. A CCD camera (BU-51LN, Bitran) placed just behind the container captures the light transmitted through the ultrasound field. The camera shutter was kept open, and light pluses were generated at a pulse repetition frequency of 2.4 kHz with a time delay (DG535, Stanford Research System) that determines a phase of the instantaneous ultrasound field.

An ultrasonic atomizer (HMC-2400, Honda Electronics) was used to generate the ultrasound field. Continuous ultrasound of 2.4 MHz was irradiated by a non-focused disk-shaped transducer of 20 mm in diameter, generating a protuberance of 0 to 5 mm in height at the water surface 35 mm above the transducer. The height was controlled by the DC power supply voltage. Focused

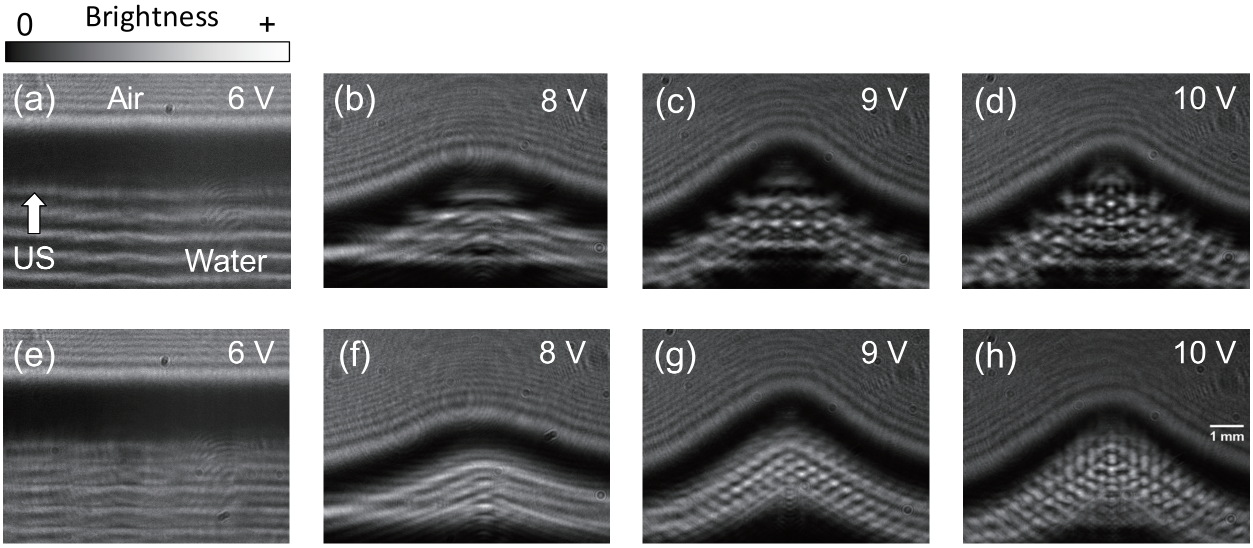

Fig. 3. Ultrasound fields generated inside a water protuberance: (a)－(d) instantaneous field images and (e)－(f) maximum intensity projection (MIP) images.

shadowgraphy visualizes refraction of light transmitting through a pressure gradient field; however, light that incidents obliquely on an air-water interface also makes refraction. Therefore, to achieve normal incidence of the light, the protuberance was generated between a space of 3 mm in width creased between a pair of glass plates as shown in Fig. 2.

3. Results and discussion

Figs. 3(a) － (d) show instantaneous ultrasound fields captured at four increasing voltage settings of the DC power supply from 6－10 V. Fig. 3(a) is the condition without a protuberance. A dark region between the water and air is produced by refraction of light transmitting through the water for which the surface was deformed by its surface tension. Straight wavefronts of the propagating ultrasound appeared at the interval of the ultrasound wavelength λ (≈0.6 mm). Fig. 3(b) is the condition with a protuberance of about 3 mm in height. Wavefronts reflected at the protuberant water surface and superimposed on the straight wavefronts were visualized. Figs. 3(c) and 3(d) are the conditions with a protuberance of about 4.5 mm in height. Interference of the propagating and reflecting wavefronts produces arrays of bright spots, which have a higher contrast in (d).

Figs. 3(e)－3(h) show maximum intensity projection (MIP) images created using 10 images of instantaneous ultrasound fields captured at delay times of 42 ns in an interval. Fig. 3(e) shows straight wavefronts that appeared at the interval of λ/2, indicating generation of a standing wave field. Fig. 3(f) shows wavefronts parallel to the water surface of the protuberance, and their brightness was the highest at the center of the protuberance. Wavefronts parallel to the surface of the protuberance can also be seen in Fig. 3(g); however, the linear wavefronts observed in Fig. 3(f) were transformed into arrays of bright spots, and their contrast was higher in Fig. 3(h). The appearance of focusing spots is similar to that observed in images captured using a resin foam container [1], indicating the usefulness of studies on generation of complex standing wave fields using the container.

4. Conclusion

To achieve correct dosimetry of ultrasound exposure on cells cultured inside a Petri dish, ultrasound fields inside a protuberance by an atomizer were visualized using a focused shadowgraphy technique. Observations revealed that arrays of focusing spots with high ultrasound pressure were generated inside the protuberance, providing important information for understanding the mechanisms of ultrasonic atomization.

References

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