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Characterization of an Acoustic Field in Ultrasonic Cleaning Bath

超音波洗浄槽内の音場特性評価

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1. Introduction

Physical force cleaning techniques, such as ultrasonic cleaning using the frequency range within 400 kHz–1 MHz is commonly used to remove particles from silicon wafers,1) with the batch-type cleaner which mount a plurality of wafers in a cleaning bath. Ultrasonic cleaners are expected to produce a uniform acoustic field so that wafer will be cleaned thoroughly and completely. However, over a region of the transducers, it is seen that cold spots, or areas of nonuniformity of the acoustic field are produced according to the arrangement of the transducers.2) An acoustic pressure field can be optically observed by the Schlieren method. This method is also useful for visualizing the acoustic pressure field in such ultrasonic cleaner to understand the interaction of ultrasonic waves from each transducer.

In this study, we observed an acoustic pressure field by the Schlieren method and compared with a particle residue map on wafer to investigate the relationship between the acoustic pressure field and particle removal.

2. Experimental method

Figure 1 shows the experimental setup of the conventional time-integrated Schlieren imaging system on ultrasonic cleaning bath. The system consists of a water bath made of transparent acrylic acid resin, a light-emitting diode (LED), a pair of collimate lens, a ring knife edge, and a charge coupled device (CCD) camera. The lenses are 50 mm in diameter and their focal length is 500 mm. Continuous illumination by LED was used for the imaging. Four piezo-electric transducers at resonance frequencies of 448 kHz were used. Each rectangular transducer with a size of 25 × 200 mm is glued to a stainless steel plate. The clearance of 2.5 mm is formed between each transducer for the electrical insulation. For all experiments, a power output sent to the transducers from the ultrasonic generator (Kaijo, model QUAVA) was set to 400 W (2.0 W/cm^2). As the medium, deionized water that has been saturated with air (7.4 mg/L of oxygen) was performed at room temperature (24 °C).

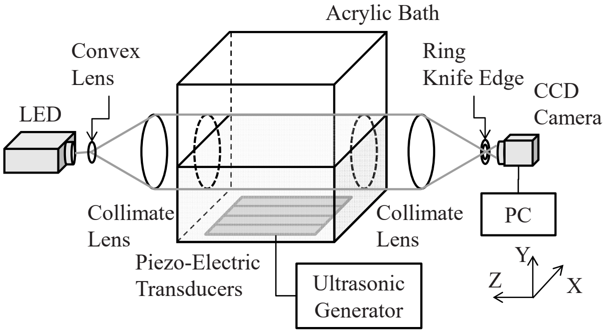

Fig. 1. Conventional time-integrated Schlieren imaging system on ultrasonic cleaning bath

3. Results and Discussion

Figure 2 shows the visualized images obtained by the schlieren system. The time of each exposure was 30 µs. A high acoustic pressure region with low brightness is formed above the transducer, while a low acoustic pressure region with high brightness is formed above the clearance. The cross-sectional brightness distribution of the transducer center in the Y axial direction was extracted and the ratio of intensity (RI) was calculated from background image / object image.

Figure 3 shows the distribution of RI and an averaged standing wave ratio (SWR) was indicated. The SWR is expressed as the ratio of the maximum and minimum amplitudes. SWR = 1 indicates a perfect traveling wave distribution, whereas SWR = ∞ means a perfect standing wave distribution.

For the direct observation of particle removal, we prepared a particle-adhering wafer. A glass wafer having 200 mm (8 inch) diameter was immersed into particle suspension so as to deposit aluminium oxide (Al_2O_3) particles as contaminants, and then natural drying was carried out.

Figure 4 shows a particle residue map with white dots representing the particle residue when a cleaning time of 10 s was applied. Particle residue was confirmed above the transducer where a predominately traveling wave field, whereas particles were removed near the liquid surface

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where a ratio of standing wave component increased from 1.09 to 1.24.

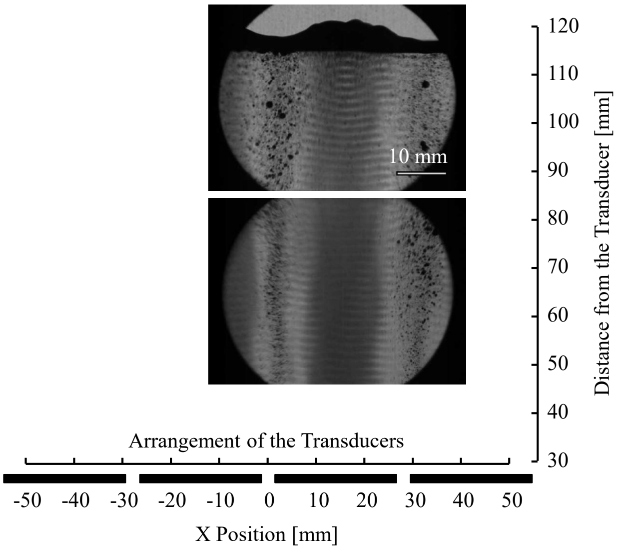

Fig. 2. Acoustic pressure field above the arrayed transducers observed by the Schlieren method.

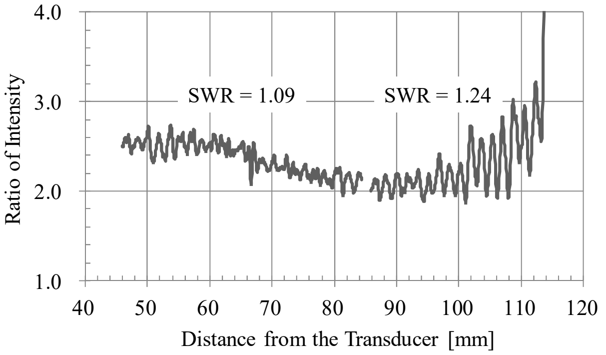

Fig. 3. Distribution of RI calculated from the cross-sectional brightness of the transducer center in the Y axial direction.

It has been explained that a bubble below the resonance size is driven toward the direction of the propagating sound wave by the force from the traveling wave component,[3] and trapped by standing waves established near the liquid surface, then particles were removed by the dynamic motions of sub-resonance size bubbles. A characteristic liquid surface relief that has a peak of displacement around the center of transducer was confirmed. The standing waves seem to be formed by following the shape of liquid surface relief.

On the other hand, particles were removed above the clearance and many visible size bubbles were formed in this region as shown in Figure 2. The increase in the bubble size occurs predominately from the coalescence of sub-resonance size bubbles at the antinodes by the actions of primary and secondary Bjerknes forces. Thus, sub-resonance bubbles seem to be transported above the clearance and trapped by standing waves. This formation of large coalesced bubbles lead attenuation of acoustic pressure above the clearance and produced a variation of the acoustic pressure field according to the arrangement of the transducers that have confirmed in Figure 2.

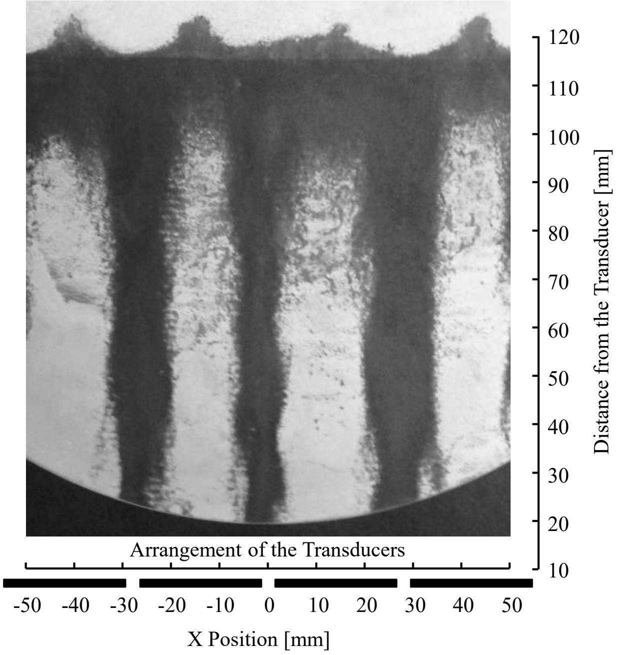

Fig. 4. Particle residue map on 200 mm diameter glass wafer.

4. Summary

In this study, we observed an acoustic pressure field in ultrasonic cleaning bath by the Schlieren method and its relation on particle removal was investigated. The results revealed that variation of the acoustic pressure field was produced according to the arrangement of the transducers. Particle residue was confirmed in the region of a predominately traveling wave field.

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References

1. K. Suzuki, Y. Imazeki, K. Han, S. Okano, J. Soejima, and Y. Koike: Jpn. J. Appl. Phys. 50 (2011) 05EC10.
2. G.W.Ferrell and L.A.Crum: J. Acoust. Soc. Am. 112 (2002) 1196.
3. J. Lee, K. Yasui, T. Tuziuti, T. Kozuka, A. Towata, and Y. Iida: J. Phys. Chem. B 112 (2008) 15333.