2Pa4-9

Proceedings of Symposium on Ultrasonic Electronics, Vol. 32 (2011) pp. 125-126
8-10 November, 2011

Dependence of Cavitation Bubbles Formation on Pulsed-wave Conditions at 1 MHz

1 MHz キャビテーション気泡形成のパルス波依存性

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1. Introduction

Ultrasonic cleaning using the megasonic frequency range within 600 kHz–1 MHz is commonly used to remove particles from silicon wafers. We previously investigated the relationship between the particle removal and the formation of cavitation bubbles. The particle removal distribution was related to the spatial distribution of visible bubbles [1], however, hole defects on a photoresist-coated wafer induced by cavitation bubble collapse, that we don't hope were observed [2]. This indicates that active bubbles may exist in the system with visible bubbles.

Pulsed-wave sonication have shown to effect the bubble structure development. With decreasing pulse ON duration, the formation of visible bubbles decreases [3]. And the pulse ON duration inadequate for the formation of active bubbles may exist. If there are no active bubbles in the system, hole defects due to active bubbles collapse will not be induced. In this study, we have investigated the effect of pulsed-wave conditions on the formation of visible bubbles and active bubbles at frequency 980 kHz.

2. Experiments

The experimental configuration used to observe the cavitation bubbles formation is shown in **Fig. 1**. Two pieces of piezo-electric transducers (35×175 mm) at resonance frequency of 980 kHz were used. The amplitude of signal sent to the transducer from the ultrasonic generator (Kaijo QUAVA) was set to equivalent of 100 W (0.8 W/cm^2) above the cavitation threshold. The power output to the transducer was measured using a megasonic power meter (Towa Electronic TDW-6102U). As the solution, deionized water and luminal solution was used at visible bubbles and sonoluminescence (SL) bubbles observation respectively. The dissolved nitrogen concentration of solution was controlled by a degassing unit. The temperature of solution was 25 °C (room temperature). The visible bubbles formations and SL bubbles formations were captured using a digital compact camera (Richo GR digital Ш). At the visible bubbles observation, the sonicated solution was illuminated with a sheet laser source from the side of the bath.

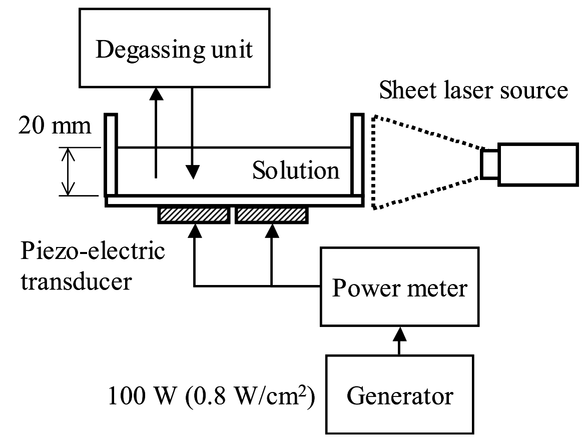

Fig. 1. Schematic of the experimental setup.

3. Results and discussion

Figure 2(a) shows the spatial distribution of visible bubbles and SL bubbles images generated at frequency 980 kHz under the continuous-wave oscillation. At the saturated condition (18 ppm N_2), coalescence could lead to the formation of large visible bubbles. These large visible bubbles are non-resonating and too large to be SL bubbles. At the degassed condition (2.5 ppm N_2), population of large visible bubbles decreased, and small visible bubbles were observed. The population of SL bubbles decreased also at the degassed condition. The population of SL bubbles decreased also compared with the saturated condition.

Figure 2(b) shows the result under the pulsed-wave oscillation. Pulse ON duration was carried out on 1.0 ms (980 cycles) and 0.8 ms (784 cycles). Pulse OFF duration was fixed to 0.2 ms (196 cycles). At the ON duration of 1.0 ms, small visible bubbles and SL bubbles were detected. And then, decreased the ON duration from 1.0 ms to 0.8 ms, no visible bubbles were observed and no SL activities were detected also. This indicates that the pulse ON duration of 0.8 ms is inadequate for the

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formation of bubbles above the active size. Additionally, we have decreased the ON duration up to 0.2 ms maintaining the output power of 100 W, and the result shows that no visible bubbles and no SL activities were observed. Therefore, ON duration below 0.8 ms is inadequate for the formation of active bubbles and the formation of active bubble is critical to certain ON duration.

A schematic of the formation of cavitaiton bubbles is illustrated in **Fig. 3**. 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. Under the continuous-wave oscillation, sub-resonance size bubbles become larger than the active size as a function of time, and eventually reach a non-resonance size that becomes detectable via coalescence. At the pulsed-wave oscillation (ON duration is 0.8 ms), as the result shown in Fig. 2 (b), it seems that the sub-resonance bubbles did not reach an active size due to the inadequate of ON duration.

In order to apply the pulsed-wave oscillation to the particle removal, confirmation of the existence of sub-resonance size bubbles in the system and the dynamic motions of sub-resonance size bubbles effect to the particles is required.

4. Conclusion

This study demonstrates that there is a critical pulse ON duration inadequate for the formation of active bubbles. Below this critical pulse ON duration, hole defect due to active bubble collapse will not be induced, and particles will be removed if the dynamic motions of sub-resonance bubbles are effective.

References

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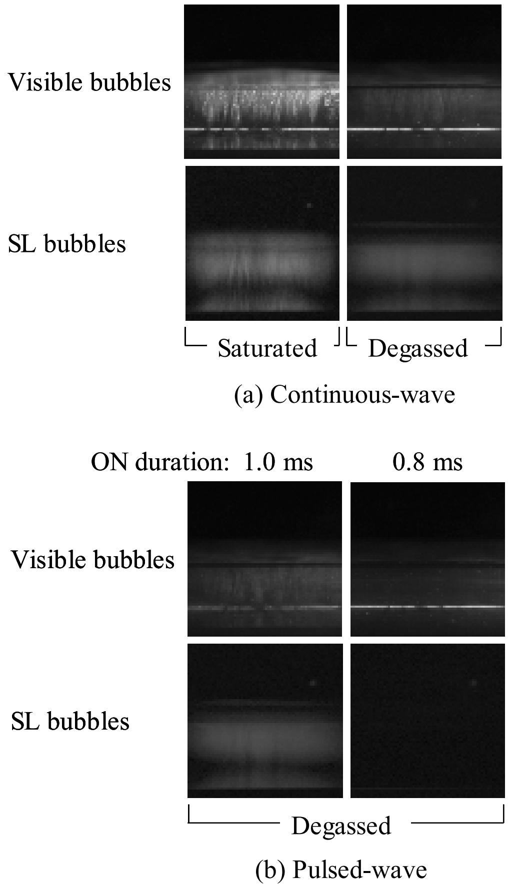

Fig. 2. Visible bubbles formation and SL bubbles formation under (a) continuous-wave and (b) pulsed-wave oscillation. Exposure time for visible bubbles and SL bubbles images are 66 ms and 60 s respectively.

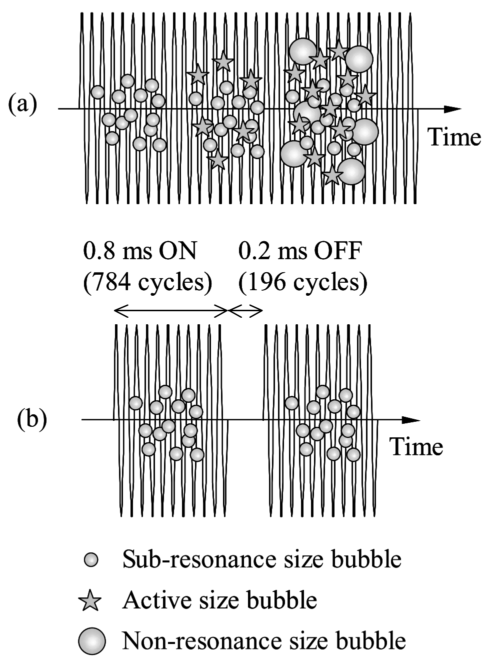

Fig. 3. Schematic of the cavitation bubbles formation under (a) continuous-wave and (b) pulsed-wave oscillation.