SINGLE BUBBLE SONOLUMINESCENCE IN INHOMOGENEOUS MEDIUM

PACS REFERENCE: 43.35.HI

HARBA Naser and HAYASHI Shigeo
Department of Applied Physics and Chemistry, University of Electro-Communications
1-5-1 Chofugaoka, Chofu, Tokyo 182-8585,Japan
Tel: +81-424-43-5496 /
Fax: +81-424-43-5794 /
E-mail:naser,hays@hl.pc.uec.ac.jp

ABSTRACT

SEEDING A GLYCEROL DROP IN THE ANTINODE OF AN ACOUSTIC STANDING WAVE FIELD IN DISTILLED DEGASSED WATER CAN PRODUCE SINGLE BUBBLE SONOLUMINESCENCE EVEN WHEN THE SURROUNDING MEDIUM IS CONTAMINATED EXTREMELY WITH DUST PARTICLES. DUST EFFECTS ON SINGLE BUBBLE SONOLUMINESCENCE DYNAMICS IN INHOMOGENEOUS MEDIUM WAS MEASURED BY MEANS OF LIGHT SCATTERING AND STROBOSCOPE IMAGING TECHNIQUES. OUR RESULTS SHOW THAT THE BUBBLE IS VERY DIM AND THE LIGHT INTENSITY CHANGES REMARKABLY FROM CYCLE TO CYCLE. THE BUBBLE IS DEFORMED FROM THE SPHERICAL SHAPE AFTER THE COLLAPSE. DUST PARTICLES CREATE HIGH INSTABILITY AND GLYCEROL DAMPS IT TO MAKE SYSTEMATIC STUDY POSSIBLE.

1. INTRODUCTION

Single-bubble sonoluminescence (SBSL) results from the intense focusing of acoustic energy by a single cavitation bubble; during the violent collapse, the gas inside the bubble becomes hot enough to emit a brief flash of light [1]. In contrast to multibubble sonoluminescence (MBSL), SBSL involves only a single bubble that becomes stabilized against shape instabilities and bubble size growth [2]. Two different instability can affect on bubble dynamics: (i) Rayleigh-Taylor instability, occurring whenever gas is strongly accelerated into a liquid, and (ii) parametric instability, arising due to accumulation of perturbations from sphericity over many oscillation periods [3,4]. The bubble grows by rectified diffusion [5] and eventually fragments and reforms; micro-jetting, surface instabilities and dancing behavior are observed [2]. Shape instabilities create a potential flow in the surrounding fluid and, when the fluid is viscous, it also generates vorticity [6]. When a bubble is surrounded with thin viscous layer, small perturbations accumulate during many cycles and affect remarkably on bubble dynamics after the collapse, leading to distortion in the bubble's rebounds [3,6]. This theoretical prediction has not been born out experimentally yet.

In this paper and in order to study the instability effects on the dynamics of SBSL bubble, a new method is introduced, an instability source was created around the bubble-water interface. A dusty-glycerol drop was injected at the anti-node of standing acoustic wave in distilled degassed water. The glycerol diffused in the water leaving a SBSL bubble, a few dust particles have collected around the bubble-water interface. The bubble jiggles due to the movement of dust particles around the interface. Dust effects on SBSL bubble dynamics and the emitted light intensity were observed by means of stroboscope imaging and light scattering techniques and to be presented in the following sections.

2. EXPERIMENTAL APPARATUS AND PROCEDURES

The experimental setup is depicted in Fig.1. A Langevin transducer, Tokin Corporation B151162, is cemented to the bottom of a high quality transparent rectangular quartz cell (Japan cell) with the inner dimensions $40 \times 40 \times 53$ mm and the thickness of 3 mm to make an acoustic resonator. The resonator was filled with distilled degassed water. A Hewlett-Packard 3325B function generator was used to drive the acoustic resonator and a Yokogawa 7058-10 power amplifier used to supply the driving voltage amplitude. A needle-type hydrophone, SEA SPRH-S-1000, was inserted into the center of the cell and the pre-amplifier, SEA A17DB, was connected to digital oscilloscope tektronics (TDS 724D) to check the operating mode. The resonator was operated in the (1,1,1) mode at a frequency of 29.5 kHz. Before every measurement, the resonator was adjusted to the resonance frequency and the driving voltage to the suitable value for SBSL bubble, then the hydrophone was taken out to avoid any effect on bubble stability.

Fig.2 illustrates a practical procedure to produce dusty-SBSL bubble in viscous water. We have poured an amount of glycerol in a dusty-glass dish. A glass dropper equipped at its end with rubber cover was used to draw a small amount of the dusty glycerol. The dropper was immersed inside the distilled degassed water in the acoustic resonator beside the antinode and the rubber cover was pressed. A tiny amount of the dusty-glycerol was dropped, then the dropper was removed gently and the glycerol was diffused very fast leaving dusty-SBSL bubble.

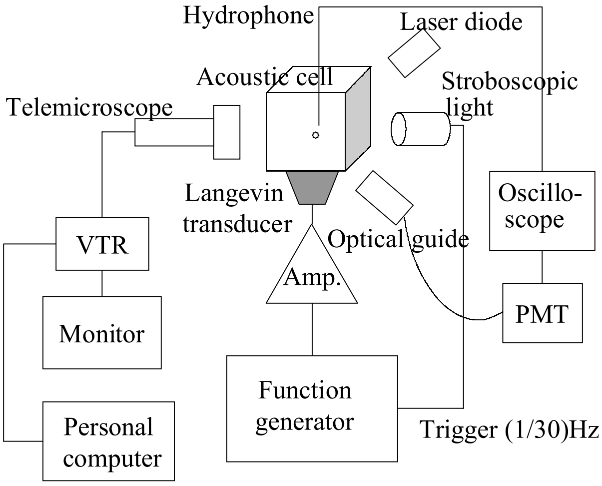

Fig.1 Experimental setup

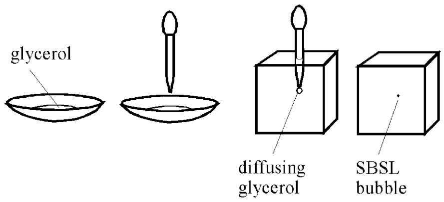

Fig.2. Practical procedures show how to Produce dusty-SBSL bubble in viscous water.

The easier way is to drop the dusty-glycerol drop at the water surface to get dusty-SBSL bubble as in the previous case, but here the dust will take sometime to collect around the bubble-water interface. The dusty-SBSL bubble was observed by stroboscope and telemicroscope, which connected to monitor and computer through VTR. A Hirox telemicroscope with working distance 75 mm was used to image the dusty-SBSL bubble. The dusty-SBSL bubble was directly illuminated by a light emitting diode (LED) which was driven by the function generator at 1/30 Hz. The number of dust particles and their motion around the bubble, particularly around the collapse were observed. The images were saved in S-VHS video recorder tape and analyzed later by Media-studio video capture program. In separate experiments, the bubble was scattered by light from laser diode of wavelength 550 nm. The scattered light was collected by photomultiplier tube PMT (Hamamatsu R269) at the large scattering 90° [7] and saved to the digital oscilloscope. The whole signals were acquired with the average of 500 traces to minimize the noise. The scattered light intensity is kept as it to avoid any change and to stress on the small changes in the bubble dynamics due to dust effects.

3. RESULTS AND DISCUSSION

Stable single bubble sonoluminescence emits stable light for millions and maybe billions of cycles. According to Lohse model [8] the bubble must fulfill four conditions: (i) The bubble must be stable agaist shape instability, which causes fragmentation. (ii) The bubble must be stable agaist rectified diffusion, which causes a grow in bubble size and the bubble fragments and emits unstable light.∙iii∙ The temperature inside the bubble must be high enough to dissociate the air and achieves completely argon rectified diffusion process. (iv) The bubble wall velocity must reach or exceed the speed of the sound in the gas, of course before the bubble radius reaches the van der waals hard-core size.

After producing the dusty-SBSL bubble, the driving voltage was reduced until the lower threshold of sonoluminescence and the bubble still emit light, any small decrease in the driving voltage amplitude will lead the bubble to the non-emitting case. Our main goal is to study dust effects on SBSL bubble in viscous water around the lower threshold of sonoluminescence.

Fig.3 shows dusty-bubble dynamics in viscous water around the lower threshold of sonoluminescence. The same bubble shows two dynamics, (a) when the bubble has spherical shape it emits light and can be observed easily by the naked eye. In contrast, (b) when the bubble shows non-spherical shape and distorted rebounds the light emission is remarkably quenched and hardly can be observed. The time difference between the two measurements (a) and (b) is 1–2 minutes. The only changed parameter is dust-particles positions around the bubble-water interface. The difference between the two-observation (a) and (b) is directly related to the dust effect on SBSL bubble dynamics and the light emission. Dust-particles lead to shape instability, which in turn leads to distorted rebounds and results in the quenching of emitted light. The distorted rebounds in Fig.3 (b) are similar in shape to the predictions of [3,6], where the idea of this paper was inspired. Dust-particles movement around the bubble, where the medium is slightly viscous, creates perturbations, which accumulate to produce parametric instability, which in turn leads the bubble to pinch off micro-bubbles in order to correct the defect in bubble dynamics.

Fig.4 shows dusty-bubble dynamics in viscous water around the lower threshold of sonoluminescence. The same bubble shows two quite different dynamics. (a) The bubble deformed from the spherical shape during the collapse, but the bubble still emits light (extremely dim SBSL). (b) There no light emission can be observed and almost the bubble emits no light (non-emitting bubble). A comparison between the two dynamics shows the difference in the ambient radius, bubble growing time, rebounds and more surprising the deformation during collapse in (a) case. The time difference between the two-measurement (a) and (b) is one minute, where the only changed parameter is the dust-particles positions. The clear difference between the two dynamics means bubble contents remarkably changes during short time. Such clear difference indicates to inhomogeneity in the medium around the bubble-water interface and maybe the dust-particles affect on mass transport between the bubble and surrounding water. The bubble alternates between argon bubble and air bubble, which means the temperature inside the bubble alternates between two different values during short time.

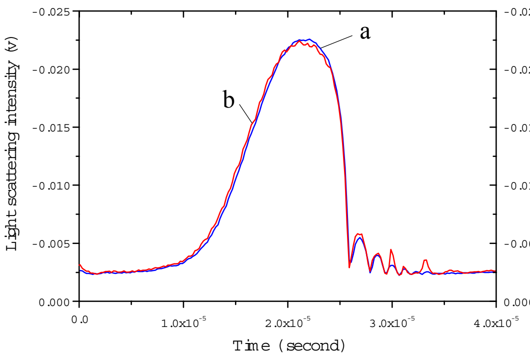

Fig.3 Dusty-bubble dynamics in viscous water (the same bubble shows two dynamics).

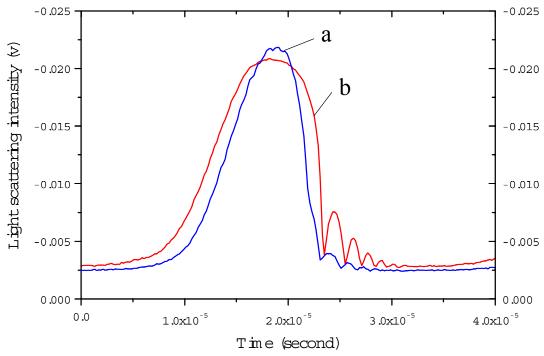

Fig.4 Dusty-bubble dynamics in viscous water (the same bubble shows two dynamics).

In the normal condition, SBSL bubble contents change very slightly within the period of oscillations and particularly the water vapor, surly dust particles movement around the bubble will increase water vapor inside SBSL bubble. When the amount of water vapor reaches a critical value, the bubble compression is not so intense and the temperature inside the bubble is low and this will enable to the onset of internal chemical reactions, which means the argon rectified diffusion is incomplete and the bubble still contain nitrogen. The critical point is the chemical reaction start during collapse Fig.4 (a), causing deformed bubble but still emitting light (extremely dim SBSL). Our interpretation is based on the hypothesis in [9] and coincides with the experimental work by Gaitan [10]. Dust-particles have altered SBSL bubble dynamics, giving rise to water vapor, where the chemical reactions start and sonochemistry can take place. Indeed Yasui [11] has found that the accumulation of surfactants around the bubble increases water vapor inside the bubble and results in the onset of chemical reactions. Argon rectified diffusion theory suggests that the dynamics of SBSL bubble depends on the percentage of inert gas within the bubble. On the other hand in MBSL the argon rectified diffusion does not take place, because the temperature within the bubble during collapse is not high enough to dissociate the air into oxygen and nitrogen. The temperature within the dusty-SBSL bubble in Fig.4 (a) maybe not high enough to rectify argon completely, which make it very weak SBSL.

It was found that dusty-SBSL bubble undergoes shape instabilities Fig.3 and rectified diffusion Fig.4 and therefore it shows unstable light as in Fig.5. Dust effect on light emission from

SBSL bubble was measured by PMT a little over the lower threshold of sonoluminescence. (a) Dusty-SBSL bubble, where the light emission changes remarkably from cycle to cycle and in (b) the light emission became close to be stable after the dust moved far. The time difference between (a) and (b) is 5 minutes.

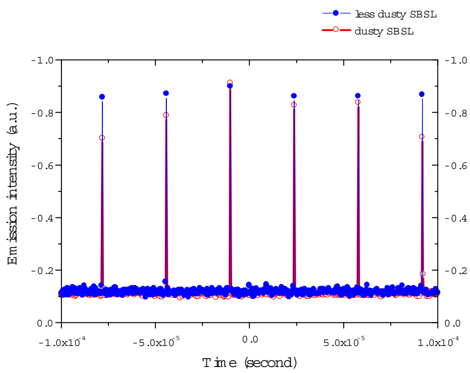

Fig.5 Emission intensity from dusty-SBSL bubble.

4. CONCLUSION

Dusty-SBSL bubble undergoes rectified diffusion, shape instability and the onset of internal chemical reactions and thus the emitted light intensity changes remarkably. Dusty-SBSL bubble represents less extreme conditions than non-dusty-SBSL bubble, due to the less effective collapse of dusty bubbles. As the sphericity of bubble collapse increases (from dusty-SBSL to the less dusty-SBSL to SBSL without dust), the efficiency of compression increases, the effective temperature within the bubble increases and the emitted light intensity increases. Dusty-SBSL bubble therefore may provide a bridge between the phenomenon of SBSL bubble and MBSL bubbles

References

- S. J. Putterman and K.R. Weninger, Annu. Rev. Fluid Mech. 32, 445-476 (2000).
- R. G. Holt and D. F. Gaitan, Phys. Rev. Lett. 77, 3791-3794 (1996).
- S. Hilgenfeldt and D. Lohse, Phys. Fluid 8 , 2808-2826 (1996).
- Y. Hao and A. Prosperetti, Physics of Fluid 11, 1309-1317 (1999).
- L. A. Crum, J. Acoust. Soc. Am. 68, 203-211 (1980).
- A. Prosperetti, Q. Appl. Math. 34, 339-351 (1977).
- S. Hayashi, Jpn. J. Appl. Phys. 38, 6562-6563 (1999).
- S. Hilgenfeldt, M. P. Brenner, S. Grossmann and D. Lohse, J. Fluid Mech. 365, 171-204 (1998).
- D. Lohse, M. P. Brenner, T. F. Dupont, S. Hilgenfeldt, and B. Johnston, Phys. Rev. Lett. 78, 1359-1362(1997.

10. D. F. Gaitan and R. G. Holt, Phys. Rev. E 59, 5495-5502 (1999).
11. K. Yasui, Phys. Rev. E 58, 4560-4567 (1998).