SINGLE BUBBLE SONOLUMINESCENCE: EFFECTS OF SIGNAL AMPLITUDE MODULATION

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1. Introduction

1.1 Single Bubble Sonoluminescence

When bubbles in a fluid are exposed to high frequency sound pressure, they emit light. This phenomenon is called sonoluminescence. Single bubble sonoluminescence is the study of a single light-emitting bubble.

To generate SBSL, a sinusoidal ultrasound signal is applied to a water-filled flask with a standing wave formation. Bjerknes force drives a small gas bubble (ambient radius of the bubble is around 5 μm [1]) towards a pressure antinode [2]. This force arises due to a pressure gradient across the bubble. Reacting to the pressure variations of the acoustic transducer, the bubble undergoes nonlinear radial oscillations. During the negative phase of the pressure swing, the bubble expands to a maximum radius of about 45 μm [1]. Next, during the positive phase, the bubble compresses, undergoing a violent supersonic collapse with bubble wall velocity in excess of 1.4 km/s [3]. This implosion is so rapid that almost no heat is able to escape the bubble. Pressure of about 1000 atm and temperatures greater then 1000 K [1] are formed inside the bubble, and the result is an emission of light.

1.2 Modulated Single Bubble Sonoluminescence

We studied SBSL for the case of driving frequency modulated by lower frequency with an offset. There exists a minimum critical pressure at which stable SL is observed. With modulated SBSL, the drive horn oscillates the acoustic pressure above and below this threshold. Our goal was to introduce the bubble into a dynamic environment, and observe the effects of amplitude modulation on the properties of the emitted light. We used this information to infer how bubble dynamics responds to the modulation.

The driving signal equation becomes:

$$f(t) = \sin(2\pi\upsilon_0 t)[a + b\sin(2\pi\upsilon t)] \qquad (1)$$

where υ_0 is the driving frequency, υ is the modulation frequency and a and b are the lowest and highest pressures over the modulation period. The modulation strength was defined as the difference of highest and lowest pressures over the modulation period:

$$\frac{a-b}{a+b}100$$

2. Experiment

The experimental setup includes a rectangular cell with dimensions 2 1/4" x 2 1/4" x 5". An oscillating voltage is applied across a piezoelectric ceramic transducer to produce ultrasound. The water-filled cell was driven in (1,1,3) mode which corresponds to resonant frequency of about 27 kHz. The drive pressure amplitude of about 1 atm was used. The bubbles are seeded by passing a brief current through a loop of NiCr wire which boils the surrounding fluid.

Modulation frequencies of 1 - 1000 Hz were used. Modulation strengths of 20%, 50%, and 80% were used in the experiments. Glycerol was added to water to produce mixtures of various viscosities. The measurements were performed for pure water and 8%, 16%, and 24% water-glycerol mixtures.

A photomultiplier tube (PMT) was used to collect the emitted light. A Tektronix TDS3000B oscilloscope was used to monitor and record the PMT signal.

To study the bubble motion, we illuminated the bubble using an external light source, and recorded its displacement using a microscope.

3. Results and Discussion

The measured SBSL signal appeared as a train of flashes[a] for modulation frequencies below 250 Hz, and as a continuous modulated signal for higher frequencies. From this we can infer that SBSL is possible and stable in the presence of amplitude modulation. For the case of small modulation frequency, the bubble goes through a cycle that repeats itself with modulation period. When the drive pressure is high enough, the bubble emits light. Consequently, as the drive pressure falls, the bubble stops emitting light.

There exists a balance between the Bjerknes, buoyancy, and viscous forces that determines the equilibrium position of the bubble. As the amplitude of the sound field decreases, the equilibrium position will shift, and the bubble will move upward away from the antinode due to buoyancy force. During the next half of the modulation period, the increasing pressure will push the bubble back towards the antinode, and the bubble will begin light emission once

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[a] Here a flash refers to a fraction of modulation period during which the bubble emits light. This, of course, consists of many hundreds of individual bubble flashes.

again. For high modulation frequencies, the bubble would not move very far away from the antinode since the modulation period is shorter. This suggests that SL intensity is position dependent since for high modulation frequencies, the bubble does not stop emitting light, but rather experiences continuous light emission with intensity oscillating with the modulation frequency.

We looked at the relationship between the flash length to modulation period ratio and the modulation frequency. We found that the ratio increases linearly as modulation frequency increases up to a frequency of about 150 Hz. At higher frequencies, the ratio of flash width to period remains constant. The bubble position responds to modulation frequency which is reflected in the increasing ratio. However, at high modulation frequencies, the changes become too rapid and the bubble is unable to respond to them. Instead, perhaps, a new equilibrium position is reached.

We found that the flash length to modulation period ratio increases as viscosity increases. Increased viscosity results in increased viscous force, which means that the bubble will move slower, and hence less away from the antinode. Increased viscosity also leads to a more symmetric collapse, and slows convection around the bubble which reduces bubble cooling.

We also examined the ratio of the time it takes for the bubble to reach the maximum light intensity, called the rise time, to the time it takes for the intensity to fall back down, called the decay time. The decay time to rise time ratio remains constant as modulation frequency is varied. As it can be seen in Figure 1, the decay time to rise time ratio decreases as modulation strength decreases and as viscosity increases. For normal SBSL, one can expect this ratio to be one. With weaker modulation, the bubble is disturbed less, which means it experiences conditions more similar to normal SBSL. This is indeed the observed behaviour.

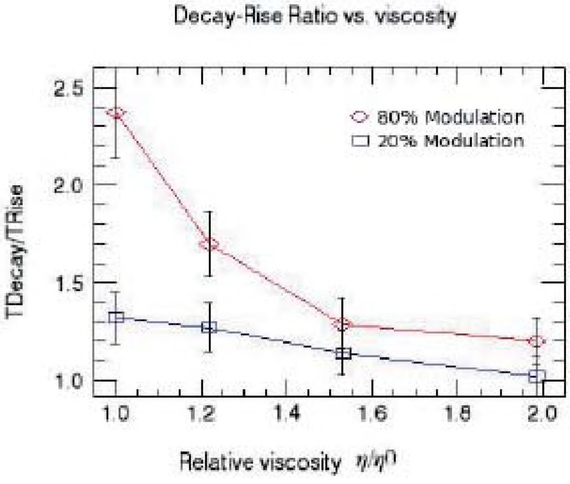

Figure 1: Decay time/Rise time ratio vs. viscosity.

As viscosity increases, bubble collapse becomes more symmetric and bubble position remains closer to the antinode, which means that bubble will again approach normal SBSL conditions.

The bubble motion responds to the pressure swings of the sound field caused by the amplitude modulation. As explained earlier, the bubble moves away from the antinode as the amplitude decreases and towards the antinode as the amplitude increases. Using side illumination and a microscope, we measured the bubble displacement (shown in Figure 2). The displacement decreases as modulation frequency increases and as modulation strength decreases.

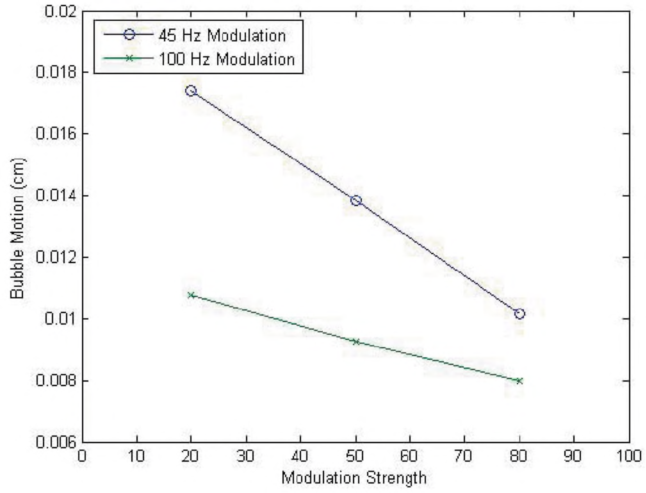

Figure 2: Bubble Motion

Spectroscopy measurements of the modulated SBSL revealed a maximum in the spectra for low modulation frequencies. This is a remarkable result, since spectra of normal SBSL show no maxima, growing steadily towards UV region. As a possible explanation, bubble cooling can take place due to contamination of the interior between flashes and subsequent longer rise times.

REFERENCES

[1] B. P. Barber, R. A. Hiller, R. Lofstedt, S. J. Putterman, K. R. Weninger, "Defining the unknowns of sonoluminescence", Physics Reports 281, 65-143 (1997).
[2] T. J. Matula, S. M. Cordry, R. A. Roy, and L. A. Crum, "Bjerknes force and bubble levitation under single-bubble sonoluminescence conditions", J. Acoust. Soc. Am. 102, 1522-1527 (1997).
[3] K. R. Weninger, B. P. Barber, and S. J. Putterman, "Pulsed Mie Scattering Measurements of the Collapse of a Sonoluminescing Bubble", Phys. Rev. Lett. 78, 1799–1802 (1997)

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