Investigation of Light Intensity of Single Bubble Sonoluminescence (SBSL) in Water and Fluorescein Sodium Solution

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ABSTRACT

Sonoluminescence is the phenomenon of mysterious conversion of acoustic energy into pulses of light. The spectrum of SBSL in water has been observed in the range of UV to IR. However, water strongly absorbs photons of wavelengths less than 200 nm and therefore, spectrum of SBSL below 200 nm has not been detected yet. In this study, the intensity of light produced by Single Bubble Sonoluminescence (SBSL) in water and Fluorescein Sodium solution 0.1 mM was measured. By adding Fluorescein Sodium to water, the intensity of SBSL was increased by 34% - 94% depending on the ambient temperature indicating that considerable amount of both visible and UV light get absorbed by water in the flask. As a result, SBSL spectrum obtained directly from water consists only a part of the full spectrum. Temperature dependence of the intensity of SBSL light was determined for deionized distilled water and water with Fluorescein Sodium.

1. INTRODUCTION

Single Bubble Sonoluminescence is observed when the interaction between a diffuse sound wave and a small isolated bubble concentrates vibrational energy by 12 orders of magnitude to produce flashes of light in the UV range as the bubble collapses [1]. SBSL has been and continues to be a subject of considerable experimental and theoretical research due to extreme conditions occur at the last stage of the bubble collapse [2-5]. The SBSL spectrum consists of a strong UV portion as well and is sensitive to the ambient temperature. SBSL in colder water produces much larger light emissions. Typically, as the water is cooled from 30 to 0 ^{o}C, the intensity of SBSL increases by a factor of 100. Flash width of the emitted light is typically of the order of a few hundred picoseconds and varies with external parameters such as forcing pressure and dissolved concentration of gases. At the last stage of the bubble collapse, the temperature inside the bubble reaches astonishingly over 15,000 K while pressure inside the bubble approaches 6000 atm [6-8]. The presence of noble gases such as Ar or Xe in the liquid increases SBSL. Besides light, there is also sound emission in SBSL which can easily be detected with needle hydrophones.

The spectrum of SBSL in water is ranging from UV (200 nm) to IR (800 nm) [9]. Water strongly absorbs photons of wavelengths less than 200 nm and therefore the UV part of the spectra below 200 nm cannot be measured correctly [10]. This inhibits the formulation of a complete theoretical model for the light emission.

It has been observed that above 200 nm wave length, the amount of SBSL light emission in water increases when ambient temperature is decreased [11]. However, the temperature dependence of light emission below 200 nm has not yet been studied. In this investigation, we determine the temperature dependence of the intensity of light emission below 200 nm. For this purpose, we employ organic fluorescent dyes to extend the regime in which the spectra can be measured. Organic fluorescent dyes e.g. Sodium Fluorescein, absorb at short wavelengths and emit at longer wavelengths and hence the intensity of UV light in the emitted spectra could be determined [12]. The same fluorescence emission spectrum is generally observed irrespective of the excitation wavelength because energy is quickly dissipated in the molecules. However the fluorescence spectrum is usually seen as a mirror image of the absorption spectrum.

2. EXPERIMENTAL METHODS

The SBSL experimental setup consists of a spherical acoustic resonator, an ultrasonic generating system, and a data acquisition system. We used a 125 ml spherical round bottomed flask of 6.5 cm outer diameter and wall thickness 2 mm as the resonator. It is acoustically driven at the resonant frequency of about 26.1 kHz. The ultrasonic sound generation part was constructed with a signal generator (Agilent 33220A), an audio amplifier and two pairs of hollow, right circular cylindrical piezoelectric transducers glued to the outer surface of the flask symmetrically.

The drive signal is delivered by an Agilent 33220A function generator through an amplifier and a tuning circuit. A pill (microphone) transducer was glued to the bottom of the flask to observe the acoustic signal of the flask. A power amplifier (300 W) was assembled to supply the sound signal having frequency above the audio frequency level. Impedance matching circuit was constructed to provide the maximum power to the transducers and it was connected to the signal generator using coaxial cables.

The first step of this experiment is to prepare host liquids. The host liquids used in this experiment are deionized distilled water and 0.1 mM Fluorescein Sodium solutions. The water sample was prepared as follows. The deionized distilled water was degassed using a vacuum pump under 25-30 mbar pressure to evacuate the residual air at 26 °C, and whisked to dissolve gases sufficiently. The process of degassing lasted about one day. Then prepared water was transferred to the acoustic resonator carefully. The setup of the experiment is shown in Figure 1. In order to generate a SBSL bubble, it is necessary to find the acoustic resonance frequency of the flask as well as the electric resonance frequency of the driving circuit. The acoustic resonance frequency of the system is found to be 26.1 kHz. It was found that the best resonance frequency is obtained when the liquid is filled up to the neck of the flask.

After resonance was obtained, a bubble was trapped in a pressure anti node located at the center of the flask by injecting little amount of water into the flask using a pipette while applying a lower sound field to the transducers. Starting from a lower value, the driving pressure was then gradually increased by changing the voltage value. The bubble became stable after passing through dancing regime. However, further increase of acoustic field kept the bubble stable and the bubble started emitting flashes of SBSL afterwards. By changing the acoustic field appropriately, it was possible to keep the bubble in any regime for long period of time.

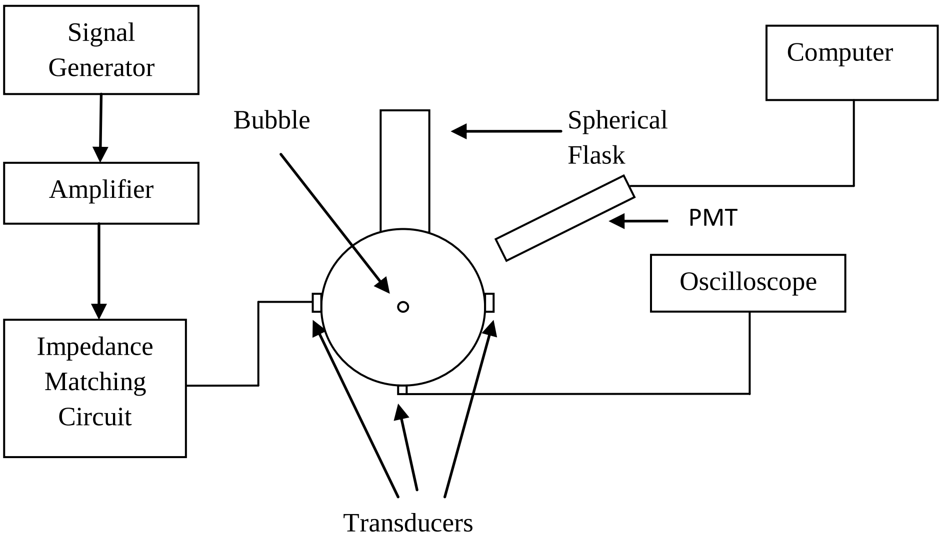

Figure 1: The experimental setup used in the experiment. A SBSL bubble is trapped in a water filled 125 ml spherical flask which is driven at its resonance frequency at 26.1 kHz by two piezoelectric disks as shown

SBSL was also successfully obtained from bubbles levitated in Fluorescein Sodium and water mixtures. A faint blue-white glow was seen from the bubble in the center of the flask. If the drive level was cautiously increased, the glow from the bubble could be made brighter, but too great increments caused the bubble to re-dissolve and disappear.

The luminescence is usually bright enough to be observed with the naked adapted eyes. However, in order to quantify the light emission, it was monitored with a detection system consisting of a photomultiplier tube (PMT - Hamamatsu H5784-04), a convex lens situated in the horizontal plane of the bubble between PMT and the flask and a DAQ card for data acquisition. The output of the PMT was sent to a computer through an analog-to-digital converter board (DAS PCI -DAS 4020/12). The PMT has an effective area of 8 mm^2 and effective wavelength range from 185 nm to 850 nm. The output of the PMT is proportional to the number of photons detected. The DAQ was set up to scan 30000 samples per second (30 k samples/s).

The position of the PMT was fixed while the resonator was placed on a stand which can be adjusted both horizontally and vertically. After a light emitting bubble was generated, the position of the resonator was adjusted to ensure that the lens is directly focused to the bubble. This way emitted light from the oscillating bubble can be focused by the lens through an aperture into the PMT.

After successfully observing SBSL in water, PMT readings were recorded for four different temperatures (13 °C, 15 °C, 18 °C, and 20 °C). Then the experiment was repeated for the Fluorescein Sodium solution 0.1 mM for the same ambient temperatures. The PMT data were analyzed to obtain light intensity and found the temperature dependence of SBSL in water and Fluorescein Sodium solutions.

3. RESULTS

Since the intensity of light is proportional to the photon count made with the PMT, the results of this investigation are presented in terms of photon counts. Photon counts of SBSL in water and Fluorescein Sodium solution 0.1 mM for various ambient temperatures are presented in Table 1. It is evident from Table 1 that as temperature increases intensity of the Sonoluminescence decreases. It is also important to note that by adding Fluorescein Sodium, the intensity of the light got increased indicating that considerable amount of both visible and UV light is absorbed by water in the flask. It is clearly notable from the last column of table 1 that when the temperature is low, large amount of light is absorbed by the water.

It was noted during the experiment that when ambient temperature is close to 20 ^oC, no light was seen for low driving pressures although the PMT produced observable photon counts.

Table 1: The measured intensity of the SBSL flashes in terms of photon count for various temperatures of water and Fluorescein Sodium solution.

Ambient Temp. (^oC)	Avg. PMT Counts			
	Deionized distilled water	0.1 mM Fluorescein Sodium solution	Difference	Percentage Difference (%)
13	11300	15168	3868	34.23
15	7597	8592	995	13.09
18	4462	5244	782	17.52
20	1067	2067	1000	93.72

4. SUMMARY AND CONCLUDING REMARKS

In this study, we have investigated the temperature dependence of the SBSL light intensity in water and dilute Fluorescein Sodium solutions. Stable SBSL is observed in Fluorescein Sodium solution with higher intensity compared to water. For both water and Fluorescein Sodium solutions, according to the photon count, the maximum intensity of the SBSL bubble is observed at the lowest ambient temperature. For temperatures close to the room temperature 25 ^oC, light emission in water is not high enough to be observed with naked eye. However, dim SBSL can be detected with a PMT. On the other hand, in the case of Fluorescein Sodium solutions, even at higher temperatures, light emission can be observed with naked eye. It was found that by adding Fluorescein Sodium, the intensity of the light in water got increased indicating that considerable amount of both visible and UV light is absorbed by water in the flask.

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