Time Resolved Measurements of Optical Emission from Sonoluminescence

D. Froula, R.W. Lee, W.C. Moss, P.E. Young

Lawrence Livermore National Laboratory, P.O. Box 808, Livermore, CA 94550

T.J. Matula

University of Washington, Seattle, WA

Abstract: Optical emission due to sonoluminescence from a collapsing gas bubble in water has been measured using an optical streak camera. Flasks have been used with measured frequency responses and temperatures to determine the dependence of the pulse duration and the jitter on temperature, driving pressure and gas concentration.

INTRODUCTION

Sonoluminescence refers to light emission from cavitating gas bubbles in a fluid. The duration of the light flash is an important observable that can be used to test the results of simulations and models. Early estimates using a photomultiplier tube (PMT) suggested that the flash duration was less than 50 ps [1]. Some models could reproduce this result with a predicted flash duration of about 10 ps [2]. Recent measurements using a two-photon correlation technique have shown that much longer (~300 ps) pulses can be observed [3] which motivates further study of the dependence of the flash pulse width on the parameters of the acoustic cell.

In this lecture, we present the results of experiments in which the sonoluminescence flash was time resolved with an optical streak camera. The use of a streak camera leads to several improvements in the measurement of the light duration: (1) high (< 10 ps) time resolution, (2) a uniquely defined time direction, and (3) very short sample times (from single event to 10 seconds). The measurements were made as a function of water temperature, driving pressure, and gas concentration.

EXPERIMENTAL DESCRIPTION

The experimental apparatus consists of a 100 ml boiling flask that is filled with water and driven at its resonance frequency (~27 kHz). A single air bubble is introduced and is suspended at the antinode of the sound field as was first demonstrated by Gaitan [4]. The gas concentration is controlled by pumping on the water; the gas concentration is determined by Henry's law and verified using an O₂ meter. It has been shown before that the light emission is determined by the presence of noble gases, in this case argon, which we assume to be present in the amount that normally occurs in air.

Thorough an acoustic cycle, the bubble radius makes an excursion from its ambient radius, \( R_0 \), to a maximum radius, \( R_{\text{max}} \), before the acoustic field compresses the bubble to its minimum radius. During the course of the experiment, we measured \( R_0 \) and \( R_{\text{max}} \) by backlighting the bubble with a nitrogen cell laser (\( \lambda = 330 \) nm) of ~100 ns duration and imaging the bubble onto a video camera with a magnification of 100 and a resolution of 2 microns. A frame grabber allows us to acquire a single event picture at any time during the acoustic cycle in order to measure the bubble radius.

The temperature was controlled by a copper cold finger that was immersed 5 mm deep into the water. The temperature of the cold finger was controlled by a thermoelectric cooler which allowed temperature stabilization to ±0.1°C during the measurements.

The drive pressure was measured using a 2 mm by 2 mm piezoelectric crystal that was located 1 cm from the bubble to minimize perturbations. The drive pressure at the bubble was extrapolated from spatial profile
measurements made with no bubble present. The hydrophone was calibrated with a B&K hydrophone as a reference. It was found that the presence of the reference hydrophone perturbed the acoustic field in the 100 ml flask, therefore the calibration was performed in a large tank. The hydrophone also provides a measure of the acoustic Q of the water-filled cell which is important for comparing results obtained in experiments at other laboratories.

The trigger for the streak camera is generated from a PMT located near the flask. The signal from the PMT goes to a low jitter trigger conditioning circuit that converts the low voltage PMT signal (~ 20 mV) to a level suitable for triggering the streak camera (> 10 V). The streak camera has an internal delay of ~ 30 ns so, in order to streak the same flash that generates the trigger, an optical delay needs to be in place. The optical delay is produced by optically relaying the light flash over a distance of ~ 20 meters to the streak camera through a unity-magnification telescope.

INITIAL RESULTS

We have obtained single event streaks when the flash intensity is sufficiently large, which generally occurs when the water is cooled. Figure 1a shows a typical single event streak when the water is cooled to 10°C; the FWHM of the pulse is approximately 300 ps. The signal-to-noise ratio can be substantially improved by integrating over many events; Figure 1b shows the pulse shape of the streak record acquired with the water at room temperature and an integration time of 5 seconds.

![Streak Camera Result](image)

Figure 1. Results from (a) a single-shot streak record at 10°C, and (b) an integrated streak signal over 5 seconds at 20°C.

Further results will be presented which show the scaling of the pulse width with the driving pressure and gas concentration at water temperatures between 8 and 20°C. The observation of asymmetric pulse shapes, which has important implications for sonoluminescence models, will also be discussed.

ACKNOWLEDGEMENTS

We thank Andy Haizi for his support. Important technical support was provided by J. Bonlie. This work was performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

REFERENCES