Time Resolved Measurements of Shock Induced Cavitation Bubbles in Various Liquids: A Novel Method of Optical Measurement

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1 Introduction

Cavitation is a major source of erosion for instance of ship propellers, pumps and water turbines. In such systems low pressure regions (pockets) exist where the water pressure suddenly becomes very low, almost a vacuum. These growing pockets, i.e. the ”cavitation bubbles” propagate to high pressure regions, where they collapse immediately.

Different methods of bubble generation are possible. One of them uses a powerful short laser pulse that is focused into a liquid and there generates an optical breakdown. During the successive plasma recombination, a fast growing nearly spherical bubble arises. When the radius has reached its maximum, the bubble contracts continuously to a minimum and finally it collapses. The onset and the collapse of the bubble are usually combined with shock wave emission (laser generated bubble and shock waves, LGBS). Following Bosset, the initial hydrodynamic bubble energy is redistributed in at least five distinct channels [1]:

1. a new subsequent bubble caused by a partially elastic rebound
2. shockwaves
3. liquid jets (in the vicinity of a solid wall)
4. electromagnetic radiation (for instance sonoluminescence)
5. thermal motion

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The life time of a cavitation bubble depends on the initial energy and usually is of the order of a few microseconds up to several milliseconds. In the case of LGBS in liquids, it is much shorter, i.e. of the order of 10 ns to a few microseconds, respectively. Consequently, although a good temporal resolution would be required in such case, this is not easy to obtain. For investigations on cavitation bubble dynamics, in general high speed cameras with 10^4 - 10^8 frames/s and a large number of time-delayed pictures have been used [2]. Other investigators used a beam-deflection method to detect LGBS. With increasing distances from the plasma these authors were able to obtain information on bubble dimension and wall velocities [3]. Alternatively, the present work reports on a novel and inexpensive optical method to enable a time resolved insight in the formation and the collapse of cavitation bubbles. The method provides also information on the resulting shock waves from the initial state until the end of the rebound process. Under the assumption of a nearly spherical bubble, the method allows the continuous measurement with temporal and spatial resolution of a complete bubble dynamics cycle.

2 Experimental Setup

The present work concentrates on the first two channels of energy redistribution as discussed in section 1. Using a Q-switched Nd:YAG-laser (laser fluence of 0.2 MJ/cm^2, 0.4 MJ/cm^2, 0.6 MJ/cm^2; τ = 6ns) for LGBS (pump) in a cuvette, two different liquids are used: glycerine and distilled water.

An expanded HeNe-laser beam in TEM00 mode (probe) is crossing the cuvette perpendicularly to the pump beam and then is detected by means of a PIN-diode. The cavitation bubble is centered in the middle of probe beam. Due to the smaller refractive index within the bubble with respect to the surrounding liquid, the bubble acts like a negative lens. As a result part of the probe is blocked and thus the temporal evolution of the diode voltage $U(t)$ depends on the temporal evolution of the bubble volume $V(t)$. Then, under the assumption of spherical bubble geometry, the radius $r(t)$ of the bubble can be calculated. The assumed spherical bubble geometry is verified by a series of CCD images during the measurements. For shocks, normally emitted at the onset and the collapse of the bubble, the experimental arrangement is similar to a Schlieren-apparatus and thus the diode signal yields $dr(t)/dt$ and thus provides information on the shock. Consequently this method monitors the complete process from plasma generation, emission of shock waves, bubble growth and bubble collapse as well as the rebound of second and subsequent bubbles. The time resolution only depends on the diode and the electronics.

3 Results and Discussion

As a first result, Fig. 1 shows the evolution of bubbles and shocks by LGBS in glycerine at atmospheric pressure obtained by the novel method discussed in section 2. Initial shock, growth and decrease of the first bubble and its collapse accompanied by a shock wave are well recognized as well as the growth and decrease of the second bubble (rebound), again accompanied by a shock wave (Fig. 1a). Even more clearly, Fig. 1b shows the signal due to the shock wave generation, obtained by the time derivative of *r(t)*.

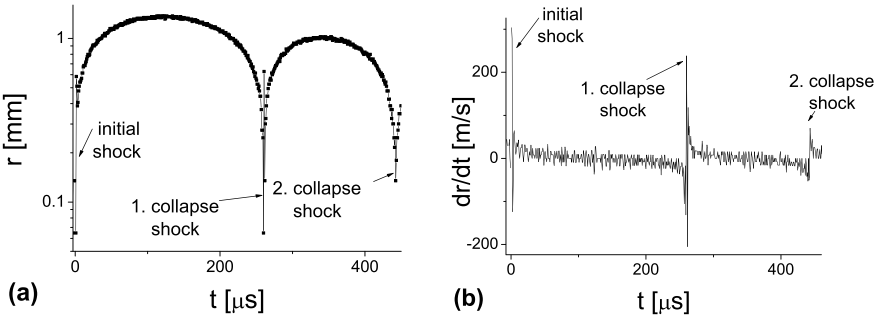

Fig. 1 Shock wave detection by a logarithmic scale of r (a) and v (b)

Fig. 2 displays bubble onset and bubble collapse in more detail and implies an almost spherical bubble structure (see section 1 and 2). However, the onset of the first bubble is difficult to observe because the initial end of the spherical shock and the onset of the first bubble are hardly separable (in Fig. 2 marked as A). In contrast, in the collapse situation a clear changeover from the bubble collapse to the shock is detectible (marked as B).

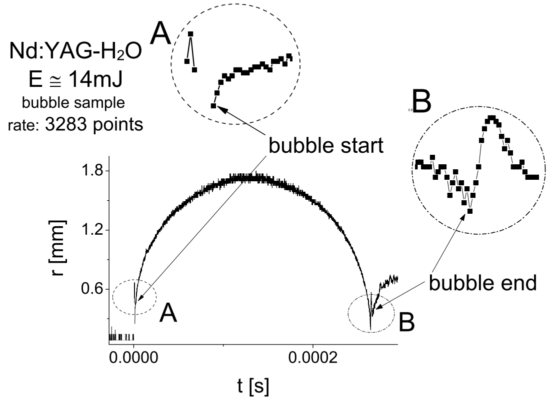

Fig. 2 Fixing of bubble start and bubble end

Single bubble dynamics in glycerine is studied also at different initial temperatures $T_0 = 20°C$, 30°C, 66°C, repectively. For $T_0 = 20°C$ no collapse or shock is visible at the end of the first and further rebound bubbles. For higher temperatures,

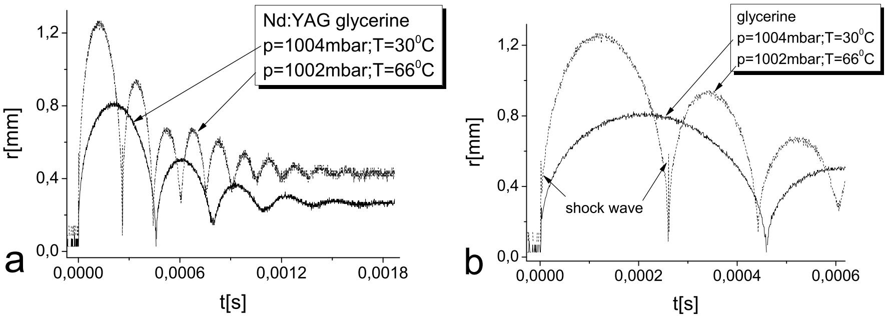

Fig. 3 Bubble life time for different liquid temperatures in glycerine (a) with inset (b)

Fig. 3 shows the bubble dynamics with a moderate time interval between onset and collapse for $T_0 = 30°\mathrm{C}$ and a much faster evolution with many rebounds for $T_0 = 66°\mathrm{C}$. In even more detail, one can recognize from Fig. 3 that shock waves are generated at $T_0 = 66°\mathrm{C}$. In total, collapse time and bubble size significantly increase with temperature.

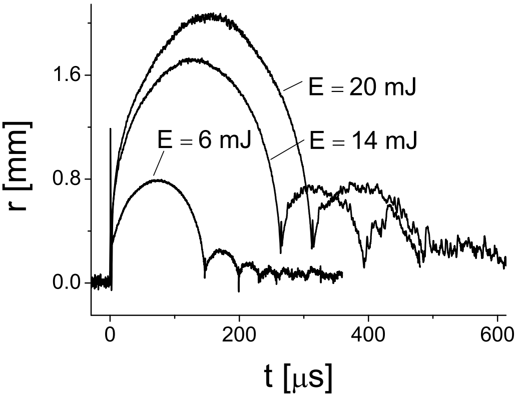

Fig. 4 Bubble life time for different laser energies in distilled water

Further measurements on LGBS are performed with distilled water (Fig. 4). Details of the experiment and theoretical simulations are discussed elsewhere [4].

4 Summary

In conclusion, the presented optical method is a powerful tool to analyze the dynamics of laser driven cavitation bubbles in liquids (LGBS). The main advantage is the high temporal and spatial resolution of bubble dimension from the onset to the collapse. Furthermore, adjacent shocks emitted could be well detected. Presently this method is restricted to spherical bubbles as generated within the present work. However, potentially the method may be extended to other geometries. Further investigations on simultaneous determination of two-dimensional bubble evolution are in progress.

References

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