Luminescence from Spherically and Aspherically Collapsing Laser Induced Bubbles

Claus-Dieter Ohl, Olgert Lindau, Werner H. Lauterborn

Dritte Physikalisches Institut, Universität Göttingen, Bürgerstr. 48-44, D-37073 Göttingen, Germany

Abstract: Luminescence from single cavitation bubbles may give answers to phenomena observed in acoustically driven cavitation luminescence studies. We give a brief overview on recent experimental results.

SPHERICAL BUBBLE COLLAPSE

Single cavitation bubbles are produced inside a water filled cuvette through focusing of a Nd:YAG laser pulse (1,2). In contrast to experimental sonoluminescence studies (see, e.g. (3)), where a sound field drives the bubble to a large expansion, in single cavitation bubble luminescence (SCBL) the bubble expands through vaporization of liquid at the laser focus (4). The laser delivers pulses of 8 ns FWHM with a pulse energy of up to 20 mJ at the fundamental wavelength of 1064 nm. A two lens system is used to produce a mostly pointlike bubble nucleation site. Successive images of the bubble dynamics are taken with an image converter camera to study the bubble shape. A second photographic system is used to observe the luminescence event: an intensified CCD camera (ICCD) in combination with a long distance microscope. An optical resolution of the luminescence image better than 3 μm is achieved. The ICCD with a high contrast ratio between shuttered and opened state suppresses the intense continuum light emission from the dielectric breakdown process. The acoustic transients at bubble generation and at bubble collapse are recorded with a hydrophone on a digital storage oscilloscope.

The aspherical bubble collapse is investigated using a rigid boundary of adjustable height placed below the laser focus.

This technique for generation of cavitation through a laser induced dielectric breakdown allows for the creation of bubbles in a reproducible way (1,3,5). In absence of a boundary, the bubble collapses spherically and emits a single shock wave (5). Figure 1 (right) shows an image of the luminescence which occurs during the spherical bubble collapse taken with the ICCD camera. This light emission is observed when the gating time of the ICCD covers the bubble collapse, measured simultaneously from the hydrophone signal. The maximum radius of the bubble, \( R_{\text{max}} \), in Fig. 1 was determined through Rayleigh's formula (2) from the duration between bubble generation and bubble collapse \( 2T_c = 150.4 \mu s \) to \( R_{\text{max}} = 0.813 \text{ mm} \). The measured lower bound for the number of photons emitted takes into account the sensitivity of the ICCD but neglects reflection losses of the imaging optics. Figure 2 (left) is a combined plot: The measured radii, \( R_i \), of the luminescence spot (●) and the number of photons (●) for different maximum bubble sizes \( R_{\text{max}} \) is plotted. Both values show approximately linear dependence on \( R_{\text{max}} \). However, as more laser energy is fed into the bubble nucleation site, the vaporization becomes
funnel shaped (6). This leads to less spherical initial conditions and as the bubble collapse progresses, it breaks off into two spatially separated bubbles. This type of collapse leads to two distinct luminescence spots.

**FIGURE 2.** Left: Radius (•) of the measured luminescence spot in dependence on the maximum achieved bubble radius $R_{\text{max}}$ during the expansion period. The measured lower bound for the total number of photons is plotted with squares (■). The regression line gives a slope of $57 \cdot 10^6$ photons per mm $R_{\text{max}}$. Right: Light energy radiated at bubble collapse, normalized to the spherical case with different $\gamma$ values but with the same maximum radius $R_{\text{max}} = 0.8$ mm.

**ASPERICHAL BUBBLE COLLAPSE**

When the fluid flow in the surroundings of a bubble is disturbed, e.g. by a rigid boundary, the bubble dynamics at collapse is altered. As the bubble collapses, the bubble reduces its size, but the bubble wall nearer to the boundary is less strongly accelerated than the radial flow from above. An indentation at the opposite bubble wall is formed and gives rise to an additional flow, apart from the purely radial one, in direction towards the boundary. This jet flowing in direction towards the boundary forms a protrusion of the bubble wall during rebound. Images with means of high speed photography can be found, e.g. in (2). The dimensionless parameter $\gamma = s/R_{\text{max}}$ helps to characterize the bubble collapse for different bubble radii, $R_{\text{max}}$, and distances, $s$, of the bubble center from the boundary. Varying the parameter $\gamma$ from $\infty$ (the spherical case) to a smaller value increases the influence of the boundary and thus the asphericity of the bubble collapse. In Fig. 2 (right) the sensitivity of the radiated light energy on the $\gamma$ value is shown. The points give the normalized (with respect to the spherical case) energy for a fixed $R_{\text{max}}$ but different $\gamma$ values. For $\gamma \leq 3.5$ the light output is not distinguishable from the dark signal. The integrated luminescence decreases rapidly with smaller $\gamma$ values. Thus we conclude that cavitation luminescence draws from a highly spherical bubble collapse.

Laser induced cavitation bubbles may become an intrinsic tool for studies of luminescence accompanying bubble collapse. The experimental problems associated with the very small size of SBSL bubbles can be overcome with laser induced bubbles in SCBL. Further studies of luminescence from aspherical bubble collapse may elucidate the mysterious connection between SBSL and MBSL (7). From symmetry considerations, the situation investigated is already equivalent to two identical bubbles with a mutual distance of $2s$ in a free liquid. This can be considered as a first step towards the influence of bubble–bubble interaction on the light output. SCBL can also be expanded to MCBL (multi cavitation bubble luminescence). And with the additional application of a sound field, luminescence may be enhanced.

**REFERENCES**