Boosting Single Bubble SonoLuminescence with an acoustic pulse

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This work addresseses the feasibility of modifying the SBSL domain of stability [1-3] to reach more violent collapse and higher temperature. This study is conducted by focusing an acoustic pulse on a bubble in sonoluminescence regime. We reports a parametric study of the effect of this acoustic pulse by varying the time of arrival of the acoustic pulse and the amplitude of the low monochromatic pressure field driving the sonoluminescing bubble. These experimental results are compared with a numerical simulation and the validity of a uniform pressure inside the bubble is discussed.

The water temperature is 25°C, the measurement of dissolved oxygen after degasing lies between 1.0 and 1.2 mg/l and the frequency is 27855 Hz. The experimental set-up and the procedure used to focus the pulse wave are described in a previous paper[4]. However the electric voltage delivered on the 8 transducers has been multiplied by 4. An average on 44 measurements of the Mie scattering with a HeNe laser is fitted by the radius square resulting from a simulation of the Rayleigh-Plesset equation (RPE). One finds the best agreement for R_0=6 µm and P_a=1.37 atm, which corresponds well to the high threshold of the stability domain measured by Gaitan and Holt[5]. The acoustic pressures is then measured with a needle hydrophone calibrated by this estimate (P_a=1.37 atm, R_0 = 6µm). The threshold for which the bubble becomes unstable and starts to dance is 1.41 atm.

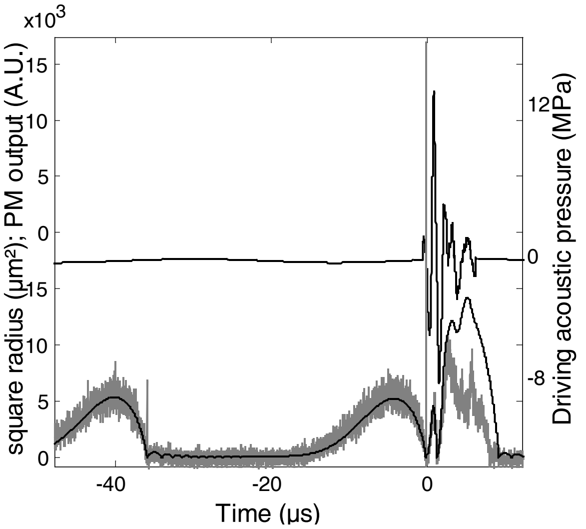

Figure 1 : Scale of right: the grey curve is the photomultiplier output, the superposed solid line is the fit by a RPE. Scale of left: the upper solid line is the applied pressure. Without the acoustic pulse, the flash would occur at t=0.

When a focused acoustic pulse is sent whith a good timing a brightness gain of about 500% is obtained, Fig. 1 scale of left, grey curve. The Mie scattering measurement shows unambiguously that the bubble dynamic is periodic before the acoustic pulse arrival. The gain is computed as the ratio between the intensity of the amplified flash and an average on the flash intensity of the 29 acoustic cycles preceding the acoustic pulse. Here Pa=1.37 atm and the pulse impinges on the bubble 0.5 µs before the end of its collapse. This behavior was simulated a RPE, Fig. 1 scale of left, black solid line.

The brightness gain varies according to the amplitude of the applied pressure of frequency 27855 Hz and its evolution is displayed on Fig. 2. For instance, gain of about 1400% is obtained for an applied pressure amplitude of 1.28 atm. Thereafter, the applied pressure amplitude is fixed at P_a = 1.37 atm just below the threshold of bubble instability measured at 1.41 atm.

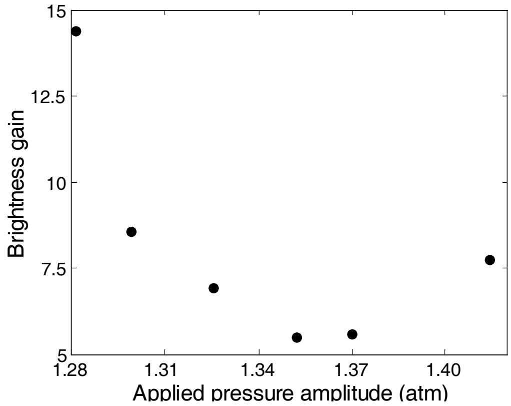

Figure 2 : Brightness gain for different applied pressure amplitudes, the pressure pulse has a constant time shift of -0.62 +/- 0.03 µs.

To study the influence of this pressure pulse on the dynamics of the bubble, the position of the pulse is shifted from -0.2 µs down to -1.1 µs, Fig. 3. Until -0.5 µs the gain is increasing; then a plateau is observed and finally a decrease starting from -0.9 µs. The interpretation of the first part of this curve is obvious: the more the pulse arrives early and the more the induced acceleration has time to affect the dynamics of the bubble leading to a faster collapse and thus to a better inertial confinement. In the second part, this effect is balanced by the braking generated by the change of sign of the acoustic pulse after 0.5 µs, i.e. the duration of the first positive half cycle, see Fig. 1 for the pulse shape. It would not occur if one were able to synthesize monopolar pressure waves. In the third part, this braking is increasingly significant and reduces the gain. Longer time shift are not presented since, in most cases, the bubble is destroyed. This threshold around -1.2 µs is probably due to bubble shape instability. This point will be discussed below.

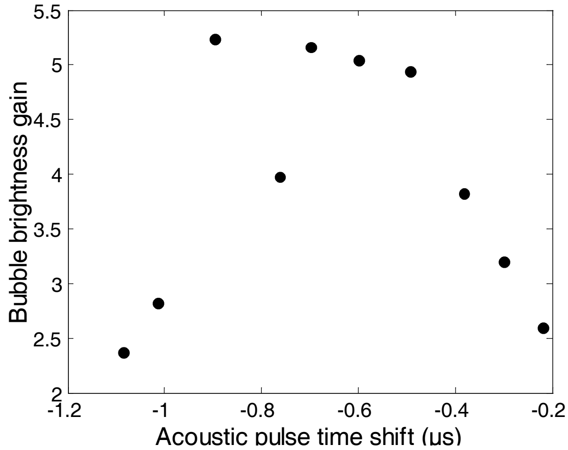

Figure 3 : Brightness gain with acoustic pulse time shift ranging from -0.2 to -1.1 µs before the normal flash location

To check the pressure uniformity assumption, the results of Lin et al[6] for homologous bubble interior dynamics are used. To this end, the values of ϵ_p is computed, Eq. 2.9 and of reference[6]. This parameters measures the pressure difference between the center and the surface of the bubble. We take the uniform Van de Waals pressure as pressure at the bubble center, $p_c(t)$. This crude approximation underestimates the variations of ϵ_p as the pressure at bubble center should more slowly increase as soon as the pressure becomes heterogeneous, ϵ_p is negative up to the end of the collapse and hence the pressure at the center is smaller than the pressure at the bubble wall. The value of ϵ_p computed by using R(t) from the preceding simulation leads to Fig. 4. Ten curves are plotted corresponding to acoustic pulse shifted from -0.2 to -1.1 µs with a -0.1µs step.

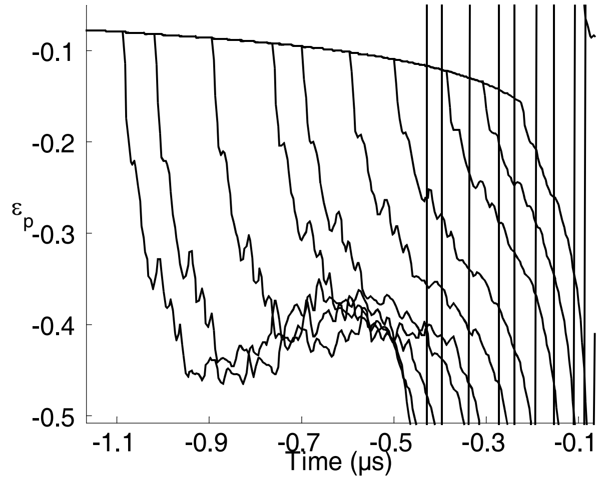

Figure 4 : Computed time evolution ϵ_p of before the first rebound for pulses arriving on the bubble between 1.1 and 0.2 µs with a step of 0.1 µs before the normal flash location.

One clearly observes a first fast variation of ϵ_p as soon as the pressure pulse hits the bubble and a second one at the end of the collapse. This result shows that the interior of the bubble cannot be regarded any more as uniform, as soon as, the acoustic pulse reaches the bubble. One can also see, the appearance of a plateau for acoustic pulse shifts lying between -0.6 and -0.9µs. This plateau is replaced by a slight bump for the longest shifts -1.0 and -1.1µs. Thus, this behavior closely matches the brightness gain variation of Fig. 3. To check the other possibility, namely the shape instability hypothesis, even longer time shifts were simulated. Only, for -1.3 µs, the acoustic pulse is strong enough and the bubble wall acceleration becomes positive before reaching the hard core radius. This threshold matches the empirically assessed bubble destruction threshold.

This simple numerical simulation captures the main characteristics of the brightness gain evolution with the time of arrival of the acoustic pulse. On the one hand, for acoustic pulse shifted of more than -1.2 µs, the bubble wall acceleration becomes positive before the minimum radius is reached. This is the necessary condition to get a Rayleigh-Taylor instability without the stabilizing mechanism of bubble expansion. On the other hand, the appearance of a plateau followed by a decrease of the brightness gain, Fig. 3, is correlated with the departure from uniform pressure inside the bubble. Indeed after the first fast decrease of ϵ_p induced by the pulse arrival, there are a plateau and even an increase for the longest time shift of the acoustic pulse, Fig. 4. The wave disturbance is generated much sooner, 500 ns before the end of the collapse, than in classical SBSL, in the last nanosecond if any, and hence has a lot of time to build up by spherical convergence. However, if this wave is launched to soon, i.e. the acoustic pulse is to weak, then the pressure tends to become uniform again before the end of the collapse.

Even if this demonstrates that the collapse is much more violent than in classical SBSL, a more complete modeling of the bubble interior dynamic is required to conclude about the existence of a shock wave. Another experimental challenge would be to measure the spectra of the boosted flash to look for a shift of the spectra weight. In any case, if the shock wave is not yet present, nothing seems to limit this method towards stronger acoustic amplitudes. This impulse technique opens a new domain of stability for SBSL for which the gas interior dynamic has to be taken into account. Reciprocally, the measured bubble brightness variation with the pulse shift could also be used to validate bubble interior dynamic and sonoluminescence models.

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