Studying cavitation and acoustic streaming by electrochemistry

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Introduction

Acoustic streaming and cavitation are fields of growing interest because of its application in chemistry or ultrasonic cleaning. Nevertheless there is still a lack of understanding of the fundamentals of bubble dynamics, especially because of the short time scales and small spatial scales that are involved.

It is well known that acoustic streaming or acoustic cavitation can enhance the mass transport towards a surface.

Birkin *et al* (1997) [1] were the first authors using electrochemistry as analytical tool for studying cavitation phenomena. Other authors as Amatore *et al* [2] or Maisonhaute *et al* [3], [4] have contributed to introduce the use of electrochemistry with microelectrodes as an indirect but fast measurement of the flow perturbation caused by acoustic cavitation. Birkin *et al* (2006) [5] proposed studying single bubbles induced by a laser, following previous work in the matter [6], with the help of simultaneous electrochemistry and high speed video measurements.

With this motivation, a project has been started, to introduce and characterize the use of electrochemistry with microelectrodes to help in a better understanding of laser pulse induced single cavitation bubbles and to characterize also acoustic streaming generated under gigasonic frequencies. In this communication, two application examples are shown to probe the possibilities of this technique and to set the basis of future investigations.

Experimental

Electrochemical measurements were performed with a Gamry Instruments Reference 600 Potentiostat (fastest time scale of 3.3 µs) and a PI x-y-z-stage for an accurate positioning of the microelectrode in an electrolyte solution. The current from reduction of $Fe(CN)_6^{3-}$ to $Fe(CN)_6^{4-}$, in the diffusion limiting regime (chronoamperometry [8]), was monitored. A Solution of 0.1 M potassium ferrocyanide (Aldrich, 99 %) and 0.5 M strontium nitrate (Aldrich, 99%) was used as electrolyte. Gold micro-disc electrodes of 10 µm and 50 µm diameter were used (sensolytics GmbH).

For the high-speed observations a Photron Fastcam SA5 camera and an Infinity K2 long distance microscope with different magnifications were employed.

Two different setups were used for the measurements. For the laser induced cavitation bubble, a nano-second pulsed Nd:YAG laser (532nm) was focused into a cuvette (20x9x6 cm^3) filled with the electroactive solution. The bubble was created always at the same position with a repeatable maximum radius of about 500µm of radius and was illuminated by a pulsed high power LED with reflectors and collimation optics. In the acoustic streaming measurements, also a special LED flash with adjustable pulse duration and power has been used. The high frequency acoustic ("gigasonic") transducer consists of an array of single emitting islands and was driven at a frequency of 1,9 GHz. To avoid overheating of the chip by the delivered 10 watts of power, it was equipped with a backside cooling. The cuvette on top of the transducer ($1\times1\times1 cm^3$) was made of PMMA.

Results

Laser pulse induced single cavitation bubbles

Evidences of high mass transfer enhancement, and consequently big flow perturbation, have been observed during these experiments. Starting frames (from maximum radius to collapse) of the high speed video are shown in Figure 1.

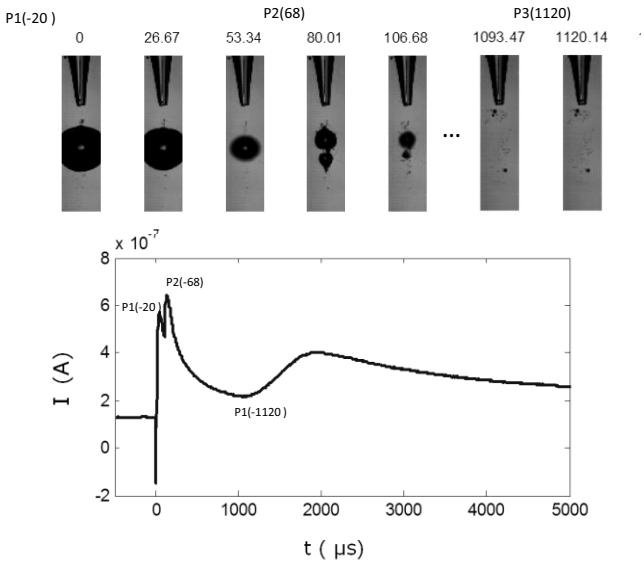

Figure 1: Top: Frames from a high speed video of a laser induced bubble showing the maximum radius to the first bubble collapse and the posterior vortex. Bottom: Chrono-amperometry measurement recorded simultaneously.

The number on the top of the frames is the time synchronized with the electrochemical measurement, and the characteristic points P1, P2, P3 are the time where principal mass transfer changes were detected in the chono-amperometry plot below. The first and second peak, P1 and P2, can be associated with expansion and collapse of the bubble, and time between these events can be easily obtained from the chronoamperogram as 88 µs. P3 is showing a secondary flow, vortex shaped, hitting the electrode around 1ms after the collapse, and producing a considerable mass

transfer, around the same order of magnitude as P1 and P2. Values of mass transfer coefficient (K_m) were calculated using equation (1) and yielded (0.02 – 0.1 cm/s), where n is the number of electrons transferred in the reaction, F is Faraday constant, A is the active surface of the electrode and C the concentration of electrolyte. These values are in good agreement when compared with those obtained by Birkin [5], taking into account differences in the experimental conditions.

$$I = K_m nFAC \quad (1)$$

The distance between electrode surface and bubble centre is an important factor in this kind of measurement. In figure 2 we show a bubble induced closer to the electrode surface and the resulting chronoamperogram. Evidence for expansion and collapse of the bubble were also measured (P1, P2) among other secondary flows (P3 and P4), the latter possibly corresponding to jetting of the bubble onto the surface.

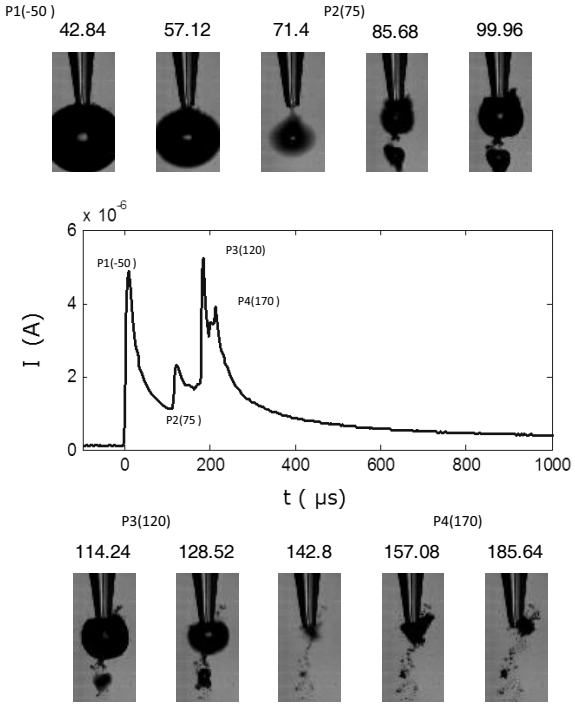

Figure 2: **Top and bottom: Frames from a high speed video of a laser induced bubble showing the maximum radius to the first bubble collapse, jetting and splitting, rebound and second collapse. Centre: Simultaneous chronoamperometry measurement.**

Acoustic gigasonic streaming

In the example in figure 3, electrochemistry has been applied to the study and characterization of an acoustic streaming flow field. Mass transfer enhancement has been obtained at different positions in the cuvette - here for decreasing distances between electrode tip and transducer centre. A very high streaming velocity zone is detected around 50 µm above the transducer surface, and a minimum near 350 µm shows up. The former corresponds to fast small eddies, while the latter is possibly connected to the centre of a larger vortex. Although there is certainly an influence of the electrode on the flow field ("invasive" method at the scales involved), it is possible to locate zones with maximum mass transfer (maximum streaming speed), and the technique might be especially useful to optimise flow or cell geometries in acoustic streaming applications, or to compare features between different transducers.

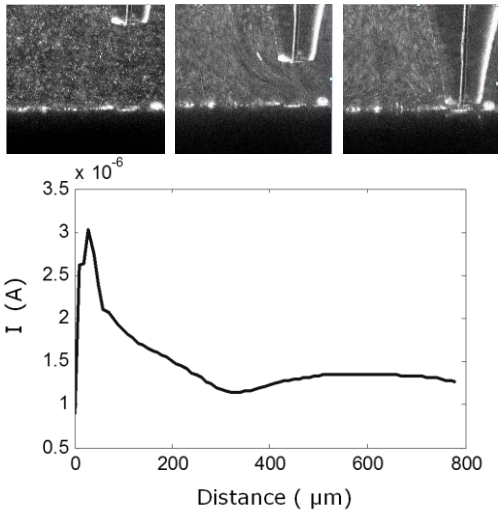

Figure 3: Top: Three different frames showing different positions of the microelectrode approaching the transducer surface (top of black image region). Bottom: Chrono-amperometry results showing mass transfer variation along vertical axis above the transducer centre.

Conclusions

Electrochemistry with microelectrodes has shown its sensibility for analysing cavitation events and acoustic streaming. Further experiments have to be done in order to know more about reproducibility and quality of the information that it is obtained with this technique.

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