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Single microbubble collapse induced by pressure waves

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Abstract: Generating single cavitation bubble on micrometer scale displays challenge on itself due to small time- and space-resolution. Generation of cavitation bubbles is possible via different methods, for example: by electric discharge, laser light, tube arrest method, ultrasound, etc. Here, we present novel method of generating single cavitation bubble on micrometer scale via generation of small vapor nucleation bubble and pressure waves. Small micrometer sized nucleation bubble is generated via local heating of magnetic bead (3 μm diameter) with laser light pulse (optical tweezer). Pressure wave is then generated with high-voltage discharge bubble collapse. Whole system is coupled with microscope and high-speed camera to acquire events on micrometer and microsecond time resolution. Bubble collapse occurs on a nanosecond scale and maximum bubble radius reaches 10-20 μm. Utilization of optical tweezer presents novel opportunity to manipulate micrometer sized particles, where ideally could be applied to study the interaction between single cavitation bubble and micrometer sized objects, for example bacterial cell.

Keywords: Single microbubble cavitation, Pressure waves, High speed video, Optical tweezer

1. Introduction

In general, most phenomena events and processes on "micro" scale are gaining more and more interest. Still, cavitation is phenomena that occurs on various scales – from macroscopic cavitation cloud all the way down to single bubble collapse. Scaling the cavitation cloud could have drastic effect on the phenomena itself [1]. Following single cavitation bubble collapse on a millimeter scale has been already characterized [2,3]. As cavitation phenomena can have inactivation effect on bacteria and other chemical-biological samples [4], thorough understanding of events on smaller microscopic scale would give us clearer answers what makes bacteria prone (or resilient) to cavitation. Generating single cavitation bubble on micrometer scale displays challenge on itself due to small time- and space-resolution. The need to follow the events under the microscope additionally challenge experimental design with space constraints around microscope. Here, we present novel method of generating single cavitation bubble on micrometer scale via generation of small nucleation vapor bubble and pressure waves. Utilization of custom-made chamber with Tungsten needles for electric discharge was fabricated to accommodate into microscope slide mount on microscope. Small nucleation vapor bubbles were generated with locally heating of magnetic beads with laser pulse. Additionally, utilization of optical tweezer

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provides vast possibilities with experiment design, whether generating organized multiple microbubbles or manipulation of biological particles (ex. bacterial cells).

2. Materials and Methods

To generate micrometer sized cavities, system of optical tweezer and high voltage electric discharge was utilized. First, the nucleation bubble of water vapor was generated with optical tweezer laser system. Optical tweezer (Aresis Tweez 300) is laser manipulation system with 1064 nm wavelength laser (nominal power 5W). Acousto-optic laser beam deflection enables manipulation of micrometer sized particles on sub-micrometer resolution. Wavelength of the laser is in near-infrared spectrum where some materials have high absorption index (ex. gold and magnetite particles, etc.) [5,6]. Irradiation with laser beam causes local heating of the material, which causes heat transfer from particle to local medium. Small micrometer sized nucleation bubble is generated via local heating of magnetic bead (Bangs Laboratories ProMag 3 Series - 3 μm diameter of particles) with high intensity laser pulse (in μsec range or longer).

Electric discharge bubble collapse was used to generate pressure waves. Piezoelectric unit was used to generate high voltage discharge. As a non-conductive medium deionized water and different sucrose solutions were used. To accurately position electric discharge in the medium, the micron sized tip of Tungsten surgical needles were used (Roboz surgical instrument RS-6065, 0,5 mm diameter, 1 μm tip). Mechanical driven piezo igniter unit was triggered via custom LabView script. Propagation of pressure waves at bubble collapse is shown in Figure 1.

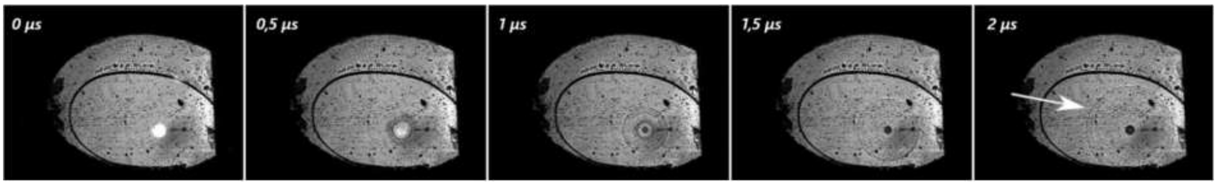

Figure 1. Cavitation bubble generates pressure waves, captured with high-speed camera.

The both systems were combined in a small chamber, 3-D printed with ABS plastic. Chamber is elliptic shaped with dimensions a = 7,5 mm, b = 5 mm and of height 4 mm. Chamber was glued to microscopic slide (Figure 2). Chamber was filled with fresh deionized water (approx. 500 μL) with addition of magnetic beads (final concentration 0,1-0,5 ‰). Filled chamber was covered with #1.5 glass coverslip and sealed with VALAP mixture (mixture of vaseline, lanoline, paraffin) [7].

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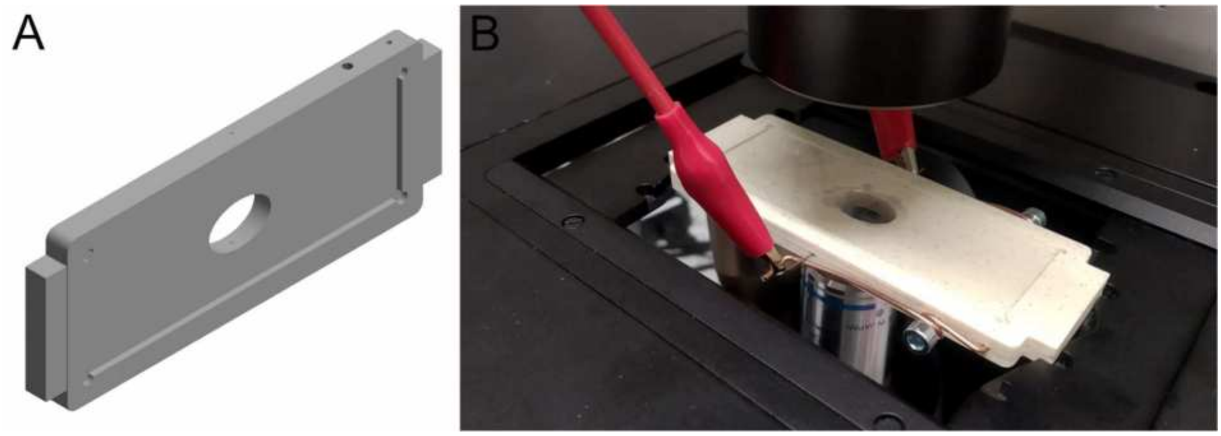

Figure 2. Custom made microscope chamber for generating single microbubble collapse with pressure waves. Schematic drawing of chamber (A) and experimental setup mounted on microscope table (B).

Experimental chamber was mounted on inverted Nikon Eclipse Ti-U with 60 x water immersion objective (Figure 2B). For visualization of microbubble collapse, microscope was coupled with high-speed camera Photron SA-Z. Video sequence of experiments were taken at 900000 fps, shutter speed 0,79 µsec, resolution 128x56 px. After mounting chamber on microscope table, we focused image to the bottom cover glass, where magnetic beads were sedimented. Then one of the magnetic bead was located on laser focus point and laser pulse was released. In the meantime, the electric discharge bubble caused propagation of shock waves which cause microbubble collapse. To simultaneously manipulate laser pulse of optical tweezer and electric discharge, custom LabView script was written.

3. Results

Optical tweezer provides sufficient laser pulse to heat the surface of magnetic bead which generates small vapor microbubbles. Diameter of vapor microbubble ranged from 1 - 4 µm with its longevity time of 10-200 msec. Pressure waves causes violent microbubble collapse in the medium with maximum radius of the bubble reaching up to 20 µm (Figure 3). Fine tuning of bubble collapse could be done with regulating distance between discharge needles, distance of nucleation bubble from discharge bubble and diameter of micrometer sized nucleation bubble.

One of the aims of this method is research of single microbubble in the vicinity of bacterial cells. First challenge was the use of deionized water which is not ideal medium for bacteria as it is hypotonic, and bacteria could burst because of osmotic pressure. Therefore, we used non-conductive sucrose solution as substitute of deionized water in experiments with bacteria. Sucrose solution is known as osmoprotectant for bacteria [8]. Brightfield imaging of low contrasted bacteria with high-speed camera proved to be demanding, but there are still lightly visible on images (Figure 3B).

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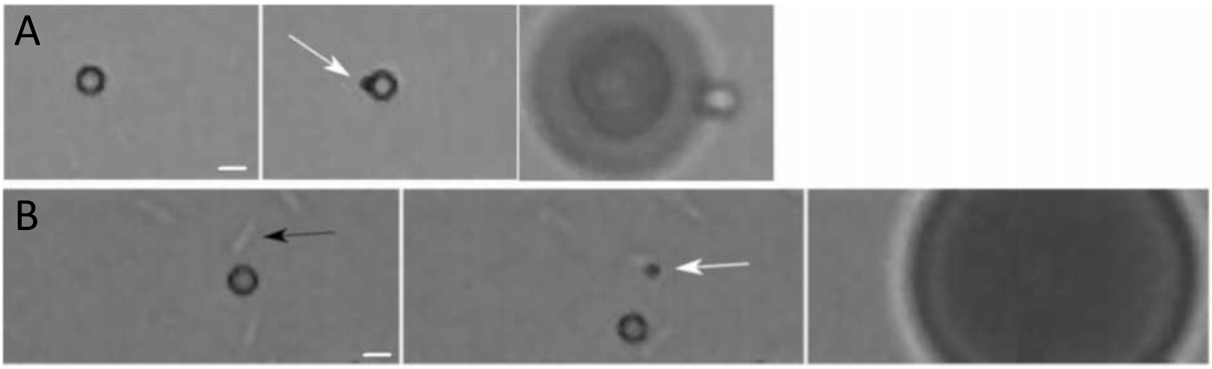

Figure 3. Sequence of micrometer sized bubble collapse; (A) first frame shows magnetic microbead in focus, then the nucleation bubble (white arrow) is generated with a laser pulse on the surface of magnetic microbead, right after that, an electric discharge is generated to promote pressure waves, which cause microbubble collapse. (B) Possible application of system for research in single bubble dynamics with interaction of bacterial cells. Black arrow shows bacterial cell in proximity of nucleation bubble. White arrow shows nucleation bubble. Scale bar represents 3 μm.

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References

[1] M. Dular, I. Khlifa, S. Fuzier, M. Adama Maiga, O. Coutier-Delgosha, Scale effect on unsteady cloud cavitation, Exp. Fluids. 53 (2012) 1233–1250. doi:10.1007/s00348-012-1356-7.

[2] M. Dular, T. Požar, J. Zevnik, R. Petkovšek, High speed observation of damage created by a collapse of a single cavitation bubble, Wear. 418–419 (2019) 13–23. doi:10.1016/j.wear.2018.11.004.

[3] J. Luo, Z. Niu, Jet and Shock Wave from Collapse of Two Cavitation Bubbles, Sci. Rep. 9 (2019) 1–13. doi:10.1038/s41598-018-37868-x.

[4] M. Zupanc, Ž. Pandur, T. Stepišnik Perdih, D. Stopar, M. Petkovšek, M. Dular, Effects of cavitation on different microorganisms: The current understanding of the mechanisms taking place behind the phenomenon. A review and proposals for further research, Ultrason. Sonochem. 57 (2019) 147–165. doi:10.1016/j.ultsonch.2019.05.009.

[5] M.K. Bhuyan, A. Soleilhac, M. Somayaji, T.E. Itina, R. Antoine, R. Stoian, High fidelity visualization of multiscale dynamics of laser-induced bubbles in liquids containing gold nanoparticles, Sci. Rep. 8 (2018) 1–12. doi:10.1038/s41598-018-27663-z.

[6] P.A. Quinto-Su, A microscopic steam engine implemented in an optical tweezer, Nat. Commun. 5 (2014) 1–7. doi:10.1038/ncomms6889.

[7] Valap Sealant, Cold Spring Harb. Protoc. . 2015 (2015) pdb.rec082917. doi:10.1101/pdb.rec082917 .

[8] K. Gouffi, V. Pichereau, J.P. Rolland, D. Thomas, T. Bernard, C. Blanco, Sucrose is a nonaccumulated osmoprotectant in Sinorhizobium meliloti, J. Bacteriol. 180 (1998) 5044–5051. doi:10.1128/jb.180.19.5044-5051.1998.

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