ナノバルブ合体挙動の液中 TEM 観察

Nanobubble dynamics during merging revealed using in-situ liquid cell electron microscopy

ナグ サルタック (九大) 正覚 雄善 (九大) 生田 竜也 (九大) 李 秦宜 (九大)
高橋 厚史 (九大) 河野 正道 (九大)

Sarthak Nag¹, Yuzen Masame², Tatsuya Ikuta², Qin-Yi Li^{2,3}, Koji Takahashi^{2,3}, Masamichi Kohno^{1,3,*}

¹ Department of Mechanical Engineering, Kyushu University, Fukuoka 819-0395, Japan

² Department of Aeronautics and Astronautics Engineering, Kyushu University, Fukuoka 819-0395, Japan

³ International Institute for Carbon Neutral Energy Research (I2CNER), Kyushu University, Fukuoka 819-0395, Japan

*Email: kohno@mech.kyushu-u.ac.jp

Macro-sized bubbles are readily observed in nature, such as in boiling water or in carbonated drinks. However, at nanoscale, the observation of bubbles is intrinsically difficult, and the phenomenon are quite exclusive. The unique aspects of these nanoscale gaseous domains, such as high stability, longevity, and surface to volume ratio, makes them interesting for numerous applications such as in bio-medical industry, oil recovery, surface cleaning, microfluidics, etc. Therefore, owing to the importance of nanobubbles in various application domains, nanobubble dynamics has been studied in this work using in-situ liquid cell electron microscopy.

Commercially available silicon nitride liquid cell electron microscopy system was used for the experiment. Thin water film (~150 nm) was encapsulated between pair of hydrophilized silicon-based chips (e-chips) equipped with 50 nm thick Si₃N₄ windows for in-situ observation. The sample was imaged using a 200 kV TEM. The interaction between the water and electron beam leads to the formation various species, with H₂ nanobubbles being dominant (*radiolysis*).

A three nanobubble system was considered and observed in this study. It was observed that a growing nanobubble induces distortion in its adjacent nanobubble, which elongates the bubble in the transverse direction (repulsive behavior). Moreover, a shrinking nanobubble also induces the distortion in neighboring nanobubbles, however, this distortion elongates the nanobubble in the radial direction (attractive behavior). These observed nanoscale phenomena were, unexpectedly, relatively gradual in nature. It has been concluded that the fluid phenomena exhibit unique characteristics at nanoscale due to the dominant intermolecular forces and has a direct influence on range of phenomenon.

In nutshell, liquid cell electron microscopy was used to study nanobubble dynamics. Nanobubble imaging using TEM was done to understand their behavior, like variations in shape and coalescence. It was observed that nanobubble merging was preceded by fluctuating interface and distortion of the bubble geometry, prominently due to the dominant nanoscale forces. The present work will enhance our understanding of the merging nanobubbles and their interactions.

References

- (1) Park, J. B. et al., *Langmuir*, 32 (2016), 11303.
- (2) Tomo, Y. et al., *Int. J. Heat Mass Tran.*, 108 (2017), 1460.