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Surface Nanobubbles Produced by Cold Water Investigated Using Scanning Transmission X-ray Microscopy

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Surface nanobubbles have received extensive attention in the past decade due to their large contact angle and long-term stability which is inconsistent with macroscopic theories. [1-4] Potential applications like surface cleaning, water pollution recovering, promoting plant growth and mineral flotation have raised significant industrial interest. [5-8] However, the commonly used techniques like transmission electron microscopy and atomic force microscopy cannot reveal the chemical composition of nanobubbles. Disputing about whether nanobubbles are indeed gas filled bubbles or other contaminations like oil droplets has caused a large confusion in the nanobubble community. Herein, synchrotron based scanning transmission X-ray microscopy (STXM) was used to investigate the gas composition inside nanobubbles and their behavior. Surface nanobubbles are produced on a reduced graphene oxide (rGO) coated silicon nitride surface with cold water method. This is a very simple and clean method to produce nanobubbles. [9] Produced interfacial nanobubbles could be imaged near O K edge by STXM with a resolution of 50nm. Surface nanobubbles which are immersed in water can be resolved at 540eV. It was also found that small nanobubbles are very stable under the x-ray irradiation while micron-sized bubbles are quite unstable and will grow larger with time. This phenomenon could be helpful to understand the super-stability of surface nanobubbles. Further analysis of the near-edge spectra could provide valuable information about the chemical composition inside surface nanobubbles.

Figure 1 shows transmission intensity images of detected nanobubbles at different photon energies near the O K-edge. There is not enough contrast at 520eV and 530eV while at least two surface nanobubble can be resolved at 540eV. Since nanobubble are immersed in water, the thickness of water over nanobubble is smaller compared to the nearby water area. This difference results in the different degree of absorption by water at 540eV which leads to the dark contrast around nanobubble. Figure 2 shows the stability of surface nanobubble under the x-ray irradiation compared with micro-sized bubble. The surface nanobubble maintains its size and shape for 94 min while micron-size bubble grew larger after 138 min [10].

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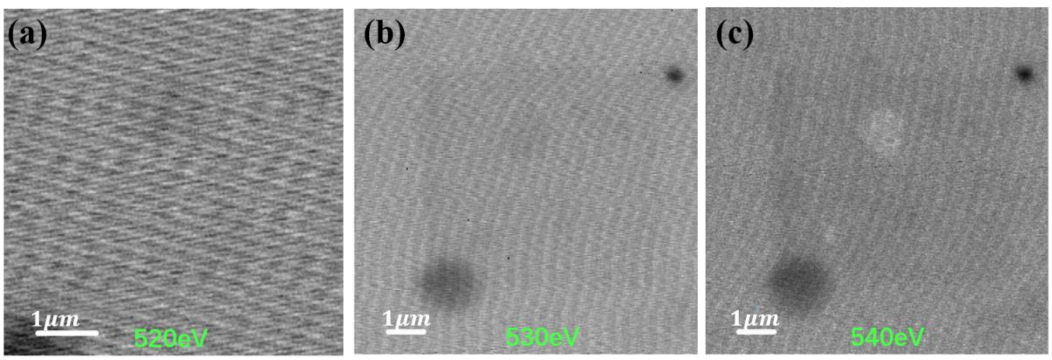

Figure 1. Transmission images of surface nanobubbles at photon energies of (a) 520eV, (b) 530eV and (c) 540eV.

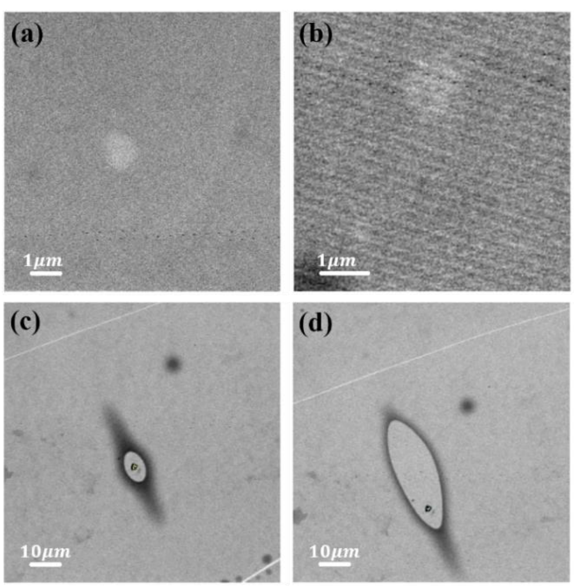

Figure 2. Changes of surface nanobubble and micron-sized bubble caused by x-ray irradiation. All images recorded at 540 eV and are transmission. (upper row) Surface nanobubble (lateral size~800 nm) at (a) 0 min, and (b) after 94 min of irradiation. (lower row) Micron-scale bubble imaged at (c) 0 min, and (d) after 138 min of irradiation. The scan size in (a) is 10 um×10 um while that in (b) is 5 um×5 um.

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