**Removal of surface-attached micro- and nanobubbles by ultrasonic cavitation**

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**Abstract**

Surface-attached micro- and nanobubbles are well known to be unresponsive to various external mechanical stresses. Recently they have been reported to show instability in strong shear flows, while in ultrasonic fields their responses are not fully investigated. We experimentally and theoretically investigate the responses of surface-attached micro- and nanobubbles to strong ultrasonic fields. In the experiments, surface-attached micro- and nanobubbles are generated in a microchannel with the standard ethanol-water exchange method. Strong ultrasonic fields are induced through the vibration of the glass substrate excited by piezoelectric elements at driving frequencies of 100 kHz to 2 MHz. At a driving frequency over 200 kHz, no responses are observed of the surface-attached micro- and nanobubbles. At a driving frequency of about 100 kHz, by contrast, ultrasonic cavitation bubbles appear in the microchannel which migrate directionally toward the surface micro- and nanobubbles. Then the surface bubbles merge with the ultrasonic cavitation bubbles and detach from the substrate, thus becoming free gaseous nuclei and experiencing ultrasonic cavitation. It is worth noting that the surface micro- and nanobubbles are removed from the substrate without observable remains. By theoretical analysis, the mutual acoustic radiation force is believed to be responsible for the directional migration of the ultrasonic cavitation bubbles. In summary, we prove in this work that surface micro- and nanobubbles can be removed from the substrate by ultrasonic cavitation bubbles and evolve into free gaseous nuclei.