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In situ UHV TEM studies on nanobubbles in graphene liquid cells

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Water, which is most abundant in Earth surface and very closely related to all forms of living organisms, has a simple molecular structure but exhibits very unique physical and chemical properties. Even though tremendous effort has been paid to understand this nature’s core substance, there amazingly still lefts much room for scientist to explore its novel behaviors. Especially, as the scale goes down to nano-regime, water shows extraordinary properties that are not observable in bulk state. One of such interesting features is the formation of nanoscale bubbles showing unusual long-term stability. Nanobubbles can be spontaneously formed in water on hydrophobic surface or by decompression of gas-saturated liquid. In addition, the nanobubbles can be generated during electrochemical reaction at normal hydrogen electrode (NHE), which possibly distorts the standard reduction potential at NHE as the surface nanobubble screens the reaction with electrolyte solution. However, the real-time evolution of these nanobubbles has been hardly studied owing to the lack of proper imaging tools in liquid phase at nanoscale. Here we demonstrate, for the first time, that the behaviors of nanobubbles can be visualized by in situ transmission electron microscope (TEM), utilizing graphene as liquid cell membrane. The results indicate that there is a critical radius that determines the long-term stability of nanobubbles. In addition, we find two different pathways of nanobubble growth: i) Ostwald ripening of large and small nanobubbles and ii) coalescence of similar-sized nanobubbles. We also observe that the nucleation and growth of nanoparticles and the self-assembly of biomolecules are catalyzed at the nanobubble interface. Our finding is expected to provide a deeper insight to understand unusual chemical, biological and environmental phenomena where nanoscale gas-state is involved.

Keywords: grapehne, liquid cell, nanobubble, UHV, TEM