Breakdown of Universal Scaling Nanometer-Sized Bubbles in Graphene

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Owing to its unrivalled elasticity and strength, graphene can hold matter at extreme pressures in the form of bubbles with dimensions down to the nanometer scale. These bubbles offer new opportunities to explore physics and chemistry and under the extreme conditions that both graphene and the trapped matter are subject to. While previous research has mostly dealt with bubbles with a radius of few nm and larger, the sub-nanometer regime remains largely unexplored. Here, we report the formation of graphene nanobubbles with radius of the order of 1 nm, which are produced using ultralow energy implantation of noble gas ions (He, Ne and Ar) into graphene grown on a Pt (111) surface [1]. We show that the universal scaling of the aspect ratio (height over radius), which has previously been established for larger bubbles (with radius of few nm and higher), breaks down when the bubble radius approaches 1 nm, as the bubble height converges to a minimum value corresponding to one atomic monolayer. Moreover, we observe that the bubble stability and aspect ratio depend on the substrate onto which the graphene is grown and on trapped element. We discuss these dependencies in terms of the role of the atomic compressibility of the noble gases as well as of the adhesion energies between the three constituents: graphene, substrate and noble gas atoms. The high strain (of the order of 10%) induced in graphene by the trapped atoms and the high van der Waals pressure (of the order of tens of GPa) inside the bubbles illustrate the unique characteristics of this sub-nanometer bubble regime, compared to the previously studied (larger) nanobubbles. We also discuss prospects to explore our approach (based on ultralow energy ion implantation) in the context of inducing periodic pseudomagnetic fields and flat bands in graphene.

References

[1] R. Villarreal, P.-C. Lin, F. Faraji, N. Hassani, H. Bana, Z. Zarkua, M. N. Nair, H.-C. Tsai, M. Auge, F. Junge, H. Hofsaess, S. De Gendt, S. De Feyter, S. Brems, E.H. Åhlgren, E.C. Neyts, L. Covaci, F.M. Peeters, M. Neek-Amal, L.M.C. Pereira, Nano Letters 21, 8103-8110 (2021).

Figures

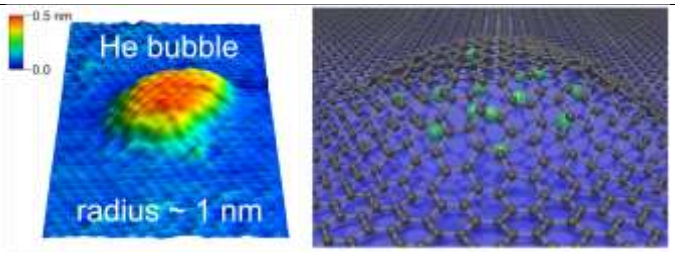

Figure 1: STM topography of a He bubble in graphene on Pt(111) and 3D atomic model.