Effects of the van der Waals interaction on the formation of wrinkles in 2D materials

Pablo Ares[1*]
Yi Bo Wang[1], Colin R. Woods[1], James Dougherty[1], Laura Fumagalli[1], Francisco Guinea[2,3,4], Benny Davidovitch[5], Kostya S. Novoselov[16,7]
[1]*Department of Physics & Astronomy and National Graphene Institute, University of Manchester, Manchester, M13 9PL, UK*
[2]*IMDEA Nanoscience, C/ Faraday 9, Madrid, 28049, Spain*
[3]*Donostia International Physics Center, Paseo Manuel de Lardizabal 4, 20018, San Sebastián, Spain*
[4]*Ikerbasque, Basque Foundation for Science, 48009, Bilbao, Spain*
[5]*Department of Physics, University of Massachusetts Amherst, Amherst MA 01003, USA*
[6]*Centre for Advanced 2D Materials, National University of Singapore, 117546, Singapore*
[7]*Chongqing 2D Materials Institute Liangjiang New Area Chongqing, 400714, China*
**Present address: Departamento de Física de la Materia Condensada, IFIMAC and INC, Universidad Autónoma de Madrid, Madrid 28049, Spain*
pablo.ares@uam.es

Instabilities and formation of complex patterns play an extremely important role in many branches of science. Understanding the origin of instabilities is key for many technologies. This topic can be revisited at the atomic level thanks to van der Waals (vdW) heterostructures of two-dimensional (2D) crystals, which allow a fine control over the parameters and an atomistic interpretation of experimental results. Here, we use Atomic Force Microscopy (AFM) to monitor the formation of instabilities consisting of wrinkles around mono- and few-layer "bubbles" in 2D vdW heterostructures [1]. Interestingly, the shape and wavelength of the wrinkles depend not only on the thickness of the 2D crystal forming the bubble, but also on the atomistic structure of the interface between the bubble and the substrate, which can be controlled by its relative orientation (twist angle). We argue that the periodicity of these patterns is the result of an energetic balance between the membrane-substrate vdW attraction, which favors small wrinkle amplitude, and the resistance of the top membrane to bending, which favors large wrinkle wavelength. We use the classical "Winkler foundation" model of elasticity theory [2] to show that the number of radial wrinkles conveys a valuable relationship between the strength of the vdW interaction and the bending rigidity of the top membrane. With this relationship, we use our data to demonstrate that, on the one hand, the bending rigidity has a nontrivial dependence on the number of layers of the top membrane, which exhibits two distinct regimes driven by interlayer slippage, and on the other hand, that the vdW force is very sensitive to interlayer alignment.

References

[1] Ares P. et al., Proc. Natl. Acad. Sci. U.S.A., 118 (2021) e2025870118
[2] Paulsen J. D. et al., Proc. Natl. Acad. Sci. U.S.A., 113 (2016) 1144-1149

Figures

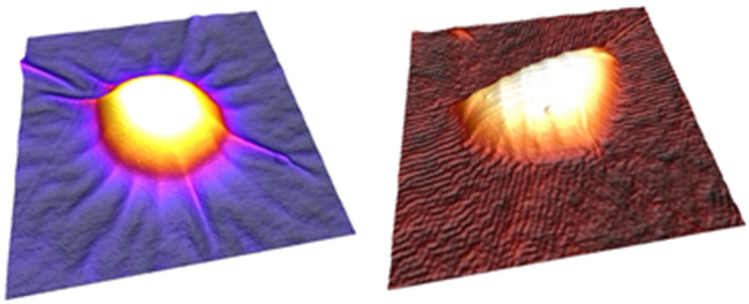

Figure 1: Wrinkles in incommensurate (left) and commensurate (right) vdW heterostructures