Understanding the structure of two-dimensional films using X-ray standing waves

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Two dimensional materials have grown significantly in importance over the last two decades. However, the term "two dimensional" is a misnomer for almost all such materials as there is always a degree of three-dimensionality due to the interaction of the material with its supporting substrate, as indicated in Figure 1.

How two-dimensional a film is, thus, an interesting question and is one that can be neatly resolved by quantitative structural measurements. X-ray standing waves has been used to determine the structure of over 15 two dimensional graphene-like films (e.g. graphene[1,2,3], boron nitride[4], silicene[5], transition metal dichalcogenides[6,7]). This work has provided the beginnings of insight into how these 2D films interact with their growth substrates from films that basically free-standing on the growth substrate [1], to those that are effectively alloyed with it [2]. Herein, I will introduce the X-ray standing wave technique and provide several key examples into how these structural measurements address the question of just how two dimensional a two dimensional material is.

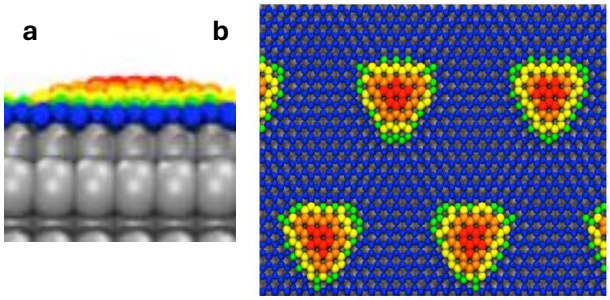

Figure 1: (a) Side and (b) plan view of graphene on Ru(0001), where the colourscale represents the variation in height of the C atoms above the surface, where blue corresponds to the lowest adsorption height and red to the highest. Reproduced from Ref. [3]

[1] J. Sforzini, et al. Physical Review Letters 114 (2015), 106804

[2] M. A. Stoodley, et al. Physical Review Letters 132 (2024), 196201

[3] C. C. Silva, et al. The Journal of Physical Chemistry C 122 (2018), 18554

[4] M. Schwarz, et al. ACS Nano 11 (2017), 9151

[5] J. T. Küchle, et al. 2D Materials 9 (2022), 045021

[6] C. C. Silva, et al. 2D Materials 9 (2022) 025003

[7] C. C. Silva, et al. Physical Review B 104 (2021) 205414