Crystal Growth in the Flatland: Growth Mechanisms in 2D Materials and Pathways to Scalable, Controlled Device Integration

Stephan Hofmann[1]

[1] Department of Engineering, University of Cambridge, UK.

sh315@cam.ac.uk

In order to serve the industrial demand for "electronic-grade" 2D materials, we focus on developing chemical vapour deposition (CVD) processes, and in this talk I will review our recent progress in scalable CVD [1] and device integration approaches of highly crystalline graphene, hexagonal boron nitride (h-BN) and transition metal dichalcogenide films (using MOCVD of WS_2 as example). The systematic use of in-situ metrology, ranging from high-pressure XPS to environmental electron microscopy, allows us to reveal some of the key growth mechanisms for these 2D materials that dictate crystal phase, micro-structure, defects, and heterogeneous integration control at industrially relevant conditions.
h-BN not only is increasingly employed as support, encapsulant and barrier for 2D material technologies, but attracted recent interest as active material particularly for defect-induced sub-bandgap single photon emission at room temperature. We developed tailored CVD processes to achieve large monolayer h-BN domains with lateral sizes exceeding 1mm, coupled to application specific transfer methods [2]. We explore super-resolution imaging as means to h-BN layer characterization [3,4], and investigated approaches to control emitter stability/behavior and density/location for potential quantum applications. We also studied the role of less straightforward growth parameters such as dissolved species in the catalyst bulk, and here will highlight the significant effects of residual bulk oxygen in graphene and h-BN growth [5]. We show that such CVD graphene can sustain mobilities of 70000 cm2/Vs at RT even when initially wet-transferred [6]. We introduce the concept of solid catalysts for epitaxial growth of a semiconductor onto a 2D substrate, using the example of Ge growth on graphene or h-BN with an Au catalyst [7]. Free-standing graphene and h-BN membranes allow us to study such forms of epitaxy directly by ETEM. With ETEM we recently also discovered how a 2D layer forms on a liquid alloy droplet, and we discuss strategies to control the presence of such 2D surface phases, using it as a tool in designing strategies for nanostructure growth.

References

1. Hofmann et al., J. Phys. Chem. Lett. 6, 2714 (2015).
2. Wang et al., ACS Nano 13, 2114 (2019); Babenko et al. submitted (2019)
3. Stern et al., ACS Nano 13, 4538 (2019).
4. Comtet et al., Nano Lett. 19, 2516 (2019).
5. Burton et al., J. Phys. Chem. C 123, 16257 (2019).
6. De Fazio et al., ACS Nano (2019) doi.org/10.1021/acsnano.9b02621
7. Periwal, Ross et al, submitted (2019).
8. Panciera et al., Adv. Mater. 31, 1806544 (2019).