Integrated Chemical Vapour Deposition of 2D Materials for Scalable Device Manufacturing

Stephan Hofmann

Department of Engineering, University of Cambridge, United Kingdom
Contact@E-mail: sh315@cam.ac.uk

In order to serve the industrial demand for "electronic-grade" 2D materials, we focus on chemical vapour deposition (CVD), 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 (TMD) films. The systematic use of in-situ metrology, ranging from high-pressure XPS to environmental electron microscopy, allows us to reveal some of the key mechanisms that dictate crystal phase, structural, defect, interfacial and heterogeneous integration control at industrially relevant conditions [2,3].
The talk will report on our approaches to reliably integrate CVD h-BN into 2DM heterostructures for scalable manufacture. This demands not only growth of large h-BN mono-layer crystals, but also their viable, clean transfer and device interfacing, for which we take high mobility graphene channels as model system. We investigate h-BN growth and transfer in unison, in particular in the context of the choice of growth catalyst, since both processes critically rely on h-BN interactions with the catalyst. Based on an understanding of the growth process, we present an improved CVD process to straightforwardly achieve large (0.5 mm or beyond) h-BN domain sizes at mono-layer coverage. Importantly we show that as-grown h-BN mono-layers can be easily and cleanly transferred using an entirely exfoliation-based approach.
We systematically explored the parameter space of atomic layer deposition (ALD) of oxides on graphene to achieve ultrathin continuous AlOx films directly on graphene [4, 5]. We developed a combination of CVD and ALD to create >90% transparent, contiguous and bendable graphene-based nanolaminate barrier films that show WVTRs below 7×10^{-3} g/m^2/day over areas of 5×5 cm^2 while being >90% optically transparent, ~10 nm thin, and manually handled in ambient. [6] Not only permeation but also a range of other properties can thereby be tuned.
We developed direct and transfer 2D material integration approaches for a large number of diverse applications, ranging from spintronics [7], to nanopore sensing [8] and THz devices [9]. Crystal growth and processing of these 2D materials reached a level where detailed, adequate characterisation over large areas has become a key challenge. Hence we also study new non-contact characterisation methods for rapid in-line monitoring [10, 11].

References

1. Hofmann et al., J. Phys. Chem. Lett. 6, 2714 (2015).
2. Weatherup et al., Nano Lett. 16, 6196 (2016).
3. Caneva et al. Nano Lett. 16, 1250 (2016).
4. Aria et al. ACS Appl. Mater. Interfaces 8, 30564 (2016).
5. Alexander-Webber et al., 2D Mater. 4, 011008 (2016).
6. Sagade et al. npj 2D Materials and Applications 1, 35 (2017).
7. Piquemal-Banci et al., Appl. Phys. Lett. 108, 102404 (2016).
8. Walker et al., ACS Nano 11, 1340 (2017).
9. Degl'Innocenti et al., ACS Photonics 3, 1747 (2016).
10. Lin et al. Sci. Rep. 7, 10625 (2017).
11. Feng et al. Nano Lett. 18, 1739 (2018).