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

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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 $7 \times 10^{-3}$ g/m²/day over areas of $5 \times 5$ cm² 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
5. Alexander-Webber et al., 2D Mater. 4, 011008 (2016).