2D Material Device Architectures: Process Optimisation and Characterisation - DTU Orbit

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A wide range of two-dimensional layered materials have been isolated and synthetically grown since the discovery of graphene. These layered materials can be thinned down to monolayer from their bulk crystals and re-stacked into arbitrary van der Waals heterostructures with atomic layer precision. The possible combinations of layers are nearly infinite, which leads to an extensive demand for robust and universal fabrication techniques and device architectures, that can enable the full potential of the extensive library of two-dimensional materials. Recent experimental development has made it possible to stack two-dimensional crystals with atomically clean interphases, through a procedure termed van der Waals assembly. We have further developed this assembly method with the ‘Hot pick-up’ method, which enables batch assembly as well as assembly with pre-patterned crystals. Inclusion of pre-patterned crystals increases the exibility of device architectures significantly.

In this work, devices and experiments have been performed with graphene, semi-conducting transition metal dichalcogenides and hexagonal boron nitride. Two robust and reliable approaches have been used. Firstly, stencil lithography has been applied in particular for process optimisation and fault-finding. Stencil lithography has the advantage of being fast, cheap and clean, and has in this thesis been applied for fabrication of graphene and transition metal dichalcogenides devices. Secondly, van der Waals heterostructures have been fabricated with both graphene and transition metal dichalcogenides layers encapsulated in hexagonal boron nitride. Electrical contacts to encapsulated graphene have been developed to accommodate the requirement of field-effect gating by top- and back gates. Devices of mono-, bi- and trilayer graphene encapsulated in hexagonal boron nitride have been fabricated and studied electrically. These devices have field-effect mobilities comparable with the highest values reported. Furthermore, state of the art nano-patterns have been fabricated into encapsulated graphene. It was also explore how graphene layers perform as tunable contacts to transition metal dichalcogenides layers encapsulated in hexagonal boron nitride. This architecture yields high performance devices, where high mobilities of the air sensitive MoTe2 crystals have measured, and metal-insulator transition have been observed in monolayer MoS2 devices. Additionally, the long-term stability of transition metal dichalcogenides has been studied, and the order of the layers has been demonstrated detectable by atomic force microscopy.

The encapsulated van der Waals heterostructures give high performance and long-term stability of two-dimensional layered materials. The integration of pre-patterned layers, post patterning of van der Waals heterostructures and detection of the layer order enables control not only of the vertical ordering of atomic layers but also in the lateral dimension, facilitating fabrication of advanced metamaterials and nano-devices with better or completely new functionalities.

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