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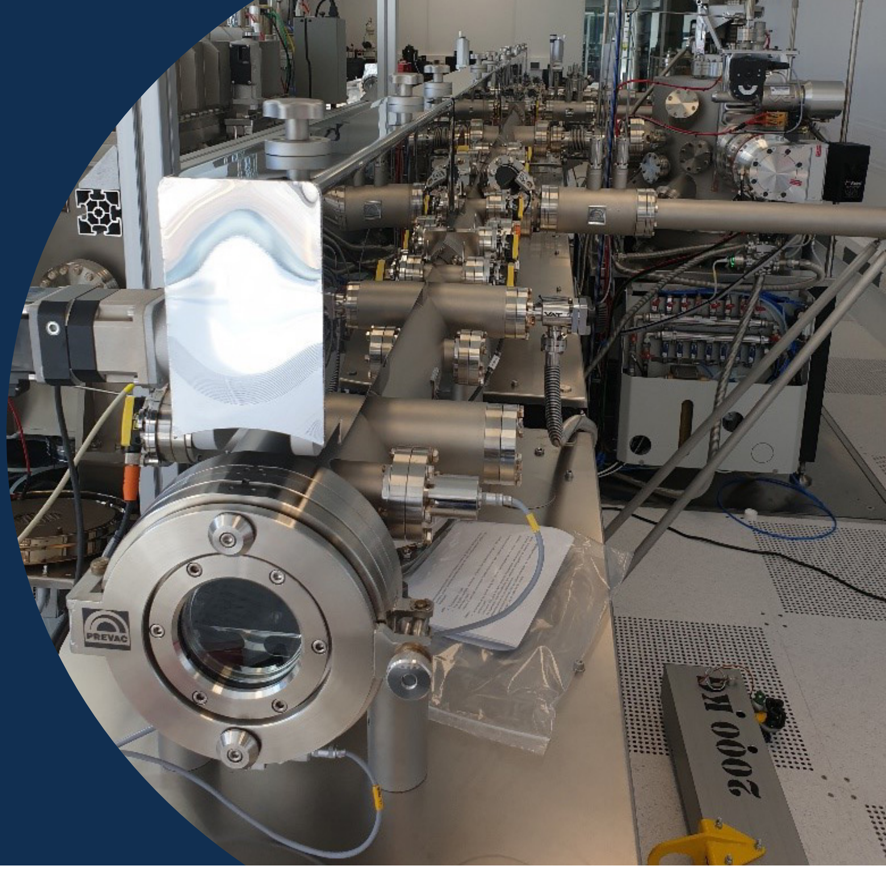

ULTRA-HIGH VACUUM FACILITY

Overview

Different mechanically exfoliated 2D crystals can be stacked into heterostructures, creating next-generation materials with unique electrical and optical properties. Some exfoliated 2D crystals must be processed within an ultra-high vacuum environment. This facility combines five capabilities, necessary for the fabrication of and processing of high-quality tailored heterostructures.

The UHV facility has the capability to: exfoliate 2D crystals under ultra-high vacuum conditions; stack multiple crystals to make heterostructures; pattern devices and contacts using *in-situ* shadow masking; metallise using electron beam and magnetron sputtering; etch and anneal prepared substrates and samples in Ar, O_2 and Ar/H_2 atmospheres.

The UHV facility is a critical component of the National Graphene Institute's fabrication machinery.

Capability profile

The UHV facility allows for the fabrication of heterostructures from exfoliated lamella materials such as graphene, H-BN and TMDCs, all under ultra-high vacuum conditions. The ability to exfoliate and encapsulate sensitive materials within an ultra-high vacuum environment allows for the creation of unique structures, previously unattainable with traditional techniques.

Core Chamber: The core chamber is the heart of the system and allows us to isolate atomically thin materials in ultra-high vacuum, granting a unique opportunity to create devices with pristine interfaces free from atmospheric contamination. It is equipped with *in-situ* optical microscopy and spectroscopy

ULTRA-HIGH VACUUM FACILITY

set-up to identify and study 2D materials. Such crystals are then assembled in a chosen sequence to produce “van der Waals heterostructures”, designer solids with customisable electronic and optical properties.

A semi-automated stacking system, which is compatible with both the common stacking techniques using PMMA, PDMS and mechanical cantilevers. There is also the capability of *in-situ* optical characterisation.

The two mechanical stages, transfer and sample, share nine degrees of freedom and each have independent heaters with maximum temperatures of 800^{O}C. A high-resolution camera, coupled with long working distance optics, allows for heterostructures to be fabricated with micron resolution.

Exfoliation can be performed in the anvil, an *in-situ* press with the capability of exfoliating many different types of source crystals under ultra-high vacuum environments.

The *in-situ* optical access allows for optical characterisation of exfoliated samples in the including, Raman spectroscopy, Photoluminescence spectroscopy and SHG.

STM Chamber: The STM allows us to image the structure of 2D crystals with atomic-scale resolution, observe atomic defects and moiré superlattices. Low temperature and high stability tunnelling spectroscopy also allows us to study the electronic structure of exotic 2D crystals, which undergo phase transitions at low temperatures, such as magnetic ordering or Bose-Einstein condensation.

The RHK STM is a commercially available 9K cryo-free STM and AFM Q+ system. The system is integrated with the rest of the UHV system to allow for the seamless transfer of samples. It operates at a base temperature of 9K and a base vacuum of 2E-10mBar.

Techniques available are: STM, Q+ AFM, Combination STM/AFM, I-V measurements, Di/Dv measurements, Standard electrical characterisation.

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Physical vapour deposition: The UHV deposition system is ideal for producing high-quality thin films of conventional metals and insulators. The deposition chamber combines magnetron sputtering and electron beam assisted deposition to produce electrical contacts directly onto the pristine interfaces of 2D heterostructures devices. When removed from the UHV chamber, these contacts can be used to study the electrical properties of a device. In addition, the deposition chamber has the capability for ion milling, which can be used to clean or pattern devices.

The ultra-high vacuum evaporator is capable of depositing thin films using either magnetron sputtering or electron beam evaporation. The system, operating at a pressure of < 1E-9 mBar, is equipped with two UHV magnetron sputter sources and an electron beam turret with four pockets. This allows for multiple materials to be evaporated, suitable for ohmic, superconducting and some insulating films.

A Shadow mask capability is being developed to allow for polymer free lithography.

Sample stage capable of heating to 1000^{o}C.

Annealing Chamber and Etching Chamber:
A high vacuum chamber capable of thermally annealing and plasma cleaning samples, in vacuum or a controlled atmosphere. The system is equipped with the following specifications:

Base vacuum: <1E-9 mBar with a cycle time of less than one hour.

Sample stage capable of heating to 1000^{o}C.

A glow discharge ring, with a maximum power of 100W.

Upstream pressure control with three different gases, Ar, O_2 and Ar/H_2.

Recipe control allows for the automation of processes.

Transfer Tunnel:
The UHV tunnel connects all of the UHV systems together. Each section can transfer into the tunnel under ultra-high vacuum conditions and allow for multiple processes to be performed without exposing the samples to atmosphere or contaminants.