Micro-transfer setup for assembling smart stacks

Recent, innovatory 2-Dimensional materials, such as graphene (a monolayer of carbon atoms) or transition metal di-chalcogenides (MoS_2, WSe_2...), can be assembled into a variety of heterostructures. These so-called "van der Waals" structures are opening up new fields for exploratory physics and applications. At the Institut NÉEL, we have developed a micro-transfer platform with a lateral mechanical-alignment precision of order one micron, which we use for making stacks of different 2D exfoliated materials.

A van der Waals heterostructure is a pile of lamellar materials where the successive layers are bound together by physical interactions (van der Waals forces) rather than by chemical bonds. The source lamellar materials are usually obtained by exfoliation of a crystal, a technique that gives single-monolayer flakes of very high crystalline quality. But these flakes are only a few tens of microns in width. Aligning a tiny sub-nm thickness flake precisely above another one, and then bringing them into perfect contact is a real challenge.

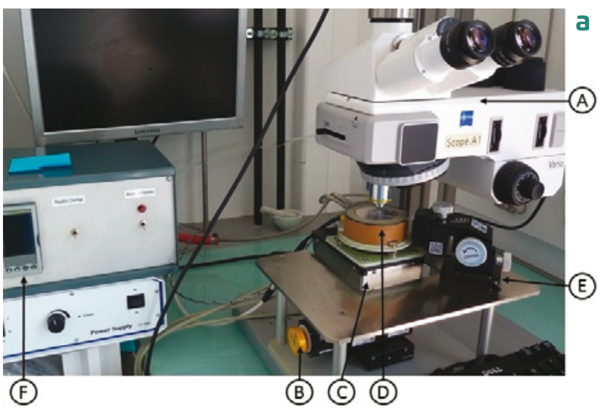


Fig. 1 (a): The micro-transfer apparatus: the microscope and display, the XYZ displacement elements, the sample-holder component and temperature controller.

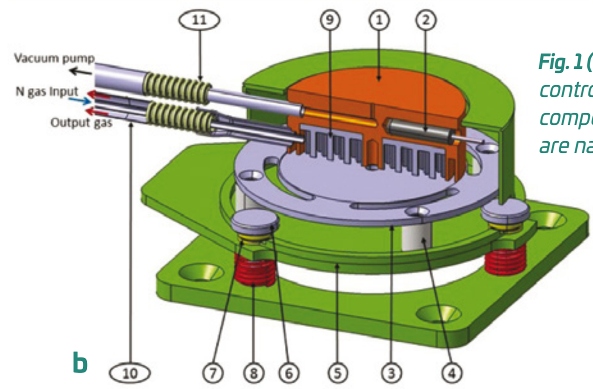


Fig. 1 (b): The temperature-controlled sample-holder component. Items A-F and 1-11 are named in the text.

Our method for assembling a pile of 3 to 10 monolayers on a substrate uses a transparent stamp to pick up, transport and deposit the layers one by one. The "stamp" is a glass slide with a spot of transparent, sticky, polymer film of PPC (polypropylene carbonate) on the under side.

Our micro-transfer platform (Fig. 1) is placed under a Zeiss Axio optical and digital microscope (A in Fig. 1a). A base-plate supports a motorized, high precision XYZ positioning system. This consists of two perpendicular horizontal motors (B) with 25 mm range, and a stepper-motorized elevator stage (C) that supports the substrate-holder part (D), providing the very precise vertical approach (200 nm steps) required during a transfer. Above the base-plate, a nickel-plated steel plateau carries a second, independent, hand-operated XYZ micro-positioner (E) (which has a magnetic base for initial placement). This positioner has a clamp to hold the glass microscope slide used to transport the flakes.

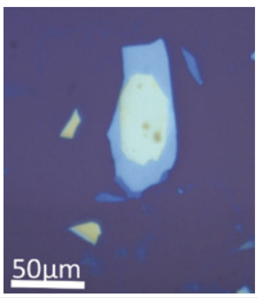
The substrate-holder part (see Fig. 1b) is fixed on the lower elevator stage. The heart of the device, the substrate holder itself, is a 2 inch diameter heating plate (>200° C) in nickel-plated copper (1 in Fig. 1b). The substrate is held over a 1 mm hole in the copper plate by aspiration (11). Thus no glueing is needed, so the plate's surface always stays clean.

The copper plate incorporates a Type J thermocouple (2) and is heated uniformly by two 175 W heating cartridges. It is supported by a stainless steel plate (3) mounted via insulating fibreglass pedestals (4) on a fibreglass screening plate (5). This has three adjusting screws (6) with spherical bearing surfaces (7), providing an angular adjustment ± 2° with respect to the XY plane, for bringing the substrate and the glass slide exactly parallel. Rapid cooling of the copper plate after a transfer operation is provided by a nitrogen gas circulation, fed via a flexible coaxial metal tube (10), through a dissipator chamber (9) inside the plate. A high precision PID (proportional-integral-derivative) temperature regulator with a Triac (electronic) output (F in Fig. 1a) stabilizes the copper plate within ±0.1 °C, essential for accurate control of the substrate temperature during the transfer.

The transfer procedure is as follows: After a lateral alignment to position the flake held on the stamp precisely above the flake on the substrate, the delicate step is contacting these two monolayer flakes together. A careful vertical displacement of the substrate enables us to see an initial zone of contact form between the substrate and the relatively thick and uneven polymer-film, at a random x,y location which can be quite far from the tiny flakes. The next, crucial step is achieved by moderate heating, which softens the polymer and enlarges the zone of contact to include the zone of interest, at a speed that depends on the speed of the temperature ramp. This provides a smooth landing for the upper flake, which binds atomically onto its target. The ultimate step is heating up to 120 °C: The polymer melts and liberates the transported monolayer flake.

Our substrate-holder unit is open to wide possibilities such as integration in a glove box, to limit oxidation and pollution of the layers. Also, the platform can precisely align mechanical masks and place single monolayers over pierced holes in a substrate, for their strain-free suspension.

Fig. 2: Optical image of a BN/Graphene/BN tri-layer realized with this system (A. Jordan, B. Sacépé). The top Boron Nitride monolayer-flake appears in pale yellow, the bottom BN flake in blue. (The graphene layer is invisible between them.)



CONTACT

Didier DUFEU
didier.dufeu@neel.cnrs.fr

Laëtitia MARTY
laetitia.marty@neel.cnrs.fr

Benjamin SACÉPÉ
benjamin.sacepe@neel.cnrs.fr

PhD student:
Goutham NAYAK
Katrin ZIMMERMANN