Multilayer Transition Metal Dichalcogenide Device Arrays Fabricated Using Nanoimprint-Assisted Shear Exfoliation (NASE)

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Atomically layered transition metal dichalcogenides (TMDCs) offer attractive electronic/ structural properties, versatile chemistry, and large natural abundance.[1] For example, as one of the most representative TMDCs, MoS_2 has emerged as a very promising material candidate for new nanoelectronic/optoelectronic applications, such as ultrasensitive chemical/bio sensors,[2] multi-bit memories,[3] and flexible photovoltaic (PV) devices with high quantum efficiencies.[4] Although a great deal of recent research effort focuses on the attractive properties associated with monolayer TMDC structures, many important nanoelectronic/optoelectronic applications, such as transistor-based memories/sensors,[2,3] photovoltaics,[4] and power TFTs, indeed demand high-quality few-layer/multilayer TMDC structures with controllable thickness. We currently lack top-down nanomanufacturing approaches capable of producing ordered arrays of such multilayer TMDC devices. In this work, we developed a new top-down approach capable of producing pristine multilayer MoS_2 fake arrays over large areas and demonstrated working FETs and biosensors made from as-produced MoS_2 flakes. These demonstrated functional devices exhibited consistent performance and held a significant potential for enabling future scale-up applications of TMDC-based electronic devices.

As illustrated in **Fig. 1**, this new approach, termed as nanoimprint-assisted shear exfoliation (NASE), consists: (a) creating a bulk MoS_2 stamp bearing pre-structured device array features; (b) pressing protrusive MoS_2 features into a polymeric fixing layer using a thermal nanoimprint process; (c) exfoliating imprinted MoS2 features along a shear direction using a roller tool. In comparison with previously reported methods for exfoliating layered materials along the vertical direction,[5,6] such a shear exfoliation process in combination with imprinted fixing layers can result in a significantly improved transfer-printing efficiency of MoS_2 features as well as the higher uniformity of MoS_2 thickness. **Fig. 2a** shows the SEM image of a bulk MoS_2 stamp bearing 20 nm high, 10 μm size pillar features. The whole stamp area is ~ 1 cm. **Fig. 2b** displays the optical micrographs of few-layer MoS_2 fake arrays imprinted and exfoliated into a polymeric fixing layer coated on a SiO_2/Si substrate. These micrographs were captured from different locations over a 1cm-size imprint area and show that NASE can result in high exfoliation efficiency and uniformity over large areas. **Fig. 3** shows transfer characteristics of multiple transistors made from NASE-produced MoS_2 flakes. These transistors exhibit consistent performance. More material/device characterization will be presented in the final presentation.

This work provides a new nanofabrication route for generating pristine TMDC device arrays with well controlled material properties, which holds significant potential to be further developed into a continuous high-throughput nanomanufacturing system capable of producing commercially viable electronic products based on emerging atomically layered materials.

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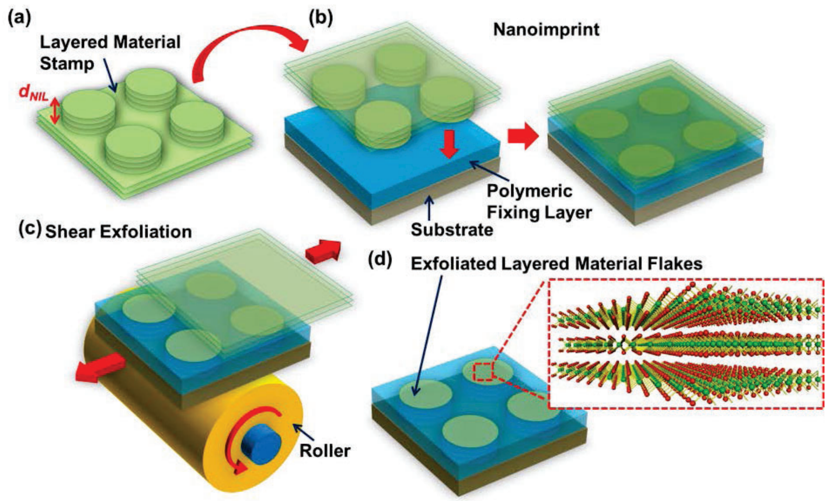

Fig. 1 Nanoimprint-Assisted Shear Exfoliation (NASE) for Manufacturing Few-Layer/Multilayer TMDC device structure arrays.

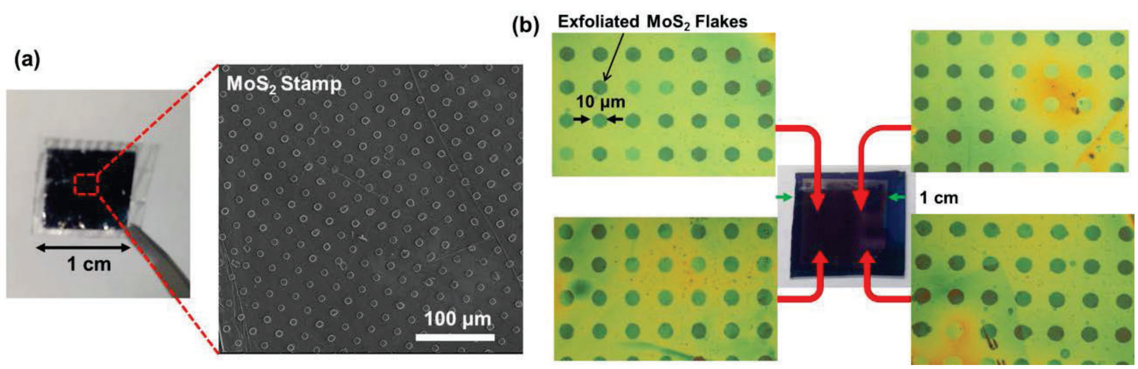

Fig. 2 (a) SEM of an exemplary bulk MoS_2 stamp bearing protrusive features (20 nm high, 10 μm size pillars); (b) optical micrographs of few-layer MoS_2 flake arrays imprinted/exfoliated into a polymeric fixing layer coated on a SiO_2/Si substrate by using NASE.

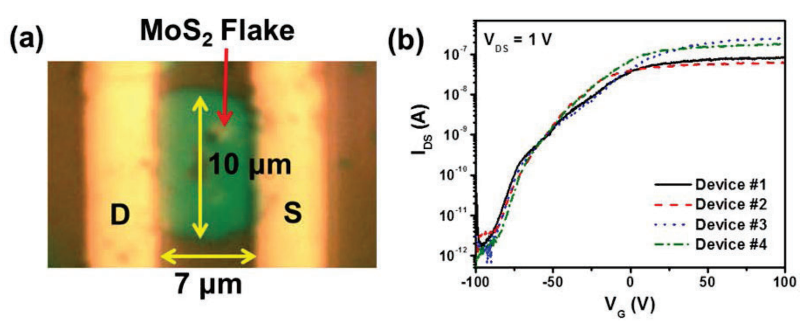

Fig. 3 (a) Optical micrograph of an exemplary back-gated FET made from a 20 nm thick MoS_2 flake that was produced by NASE; (b) transfer characteristics of multiple FETs made by NASE, which exhibit consistent performance (On/Off ratios ~ 10^5; mobility 30-40 cm^2/Vs).

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