Rubbing-Induced Site-Selective Growth (RISS) of MoS_2 Device Patterns

Byunghoon Ryu, Da Li, Chisang Park, Hossein Rokni, Wei Lu, and Xiaogan Liang*

Mechanical Engineering Department, University of Michigan, Ann Arbor, MI 48109

The excellent electronic and mechanical properties of 2D-layered transition metal dichalcogenides (TMDCs, *e.g.*, MoS_2, WSe_2, and WS_2) could be exploited to produce a broad range of functional devices with new functionalities [1]. However, the transport characteristics of such atomically-thin materials are very sensitive to the contaminants introduced by device patterning processes (*e.g.*, resist-based lithography and etching processes) [2, 3]. More seriously, such lithography-introduced contaminants cannot be safely eliminated from layered materials by conventional wafer cleaning approaches (*e.g.*, RCA and piranha methods) because such cleaning processes can chemically damage fragile layered materials. Such a challenge seriously retards the manufacturing of large arrays of TMDC-based devices with consistent characteristics. Therefore, it is highly desirable to develop site-selective growth techniques capable of directly generating TMDC device patterns, with no need of additional lithography and etching processes.

Here, we present a rubbing-induced site-selective growth (RISS) method capable of producing few-layer MoS_2 device patterns with no need of additional patterning steps. The produced few-layer MoS_2 patterns exhibit a high uniformity in thickness and can be directly used for making working electronic devices, such as field-effect transistors and memristors.

Fig. 1 shows the rubbing-induced site-selective growth (RISS) process for making few-layer MoS_2 device patterns. Specifically, **Fig. 1a** schematically illustrates the cantilever tool for performing well-controlled rubbing processes. A Si or metal-based rubbing template bearing topographic gratings is mounted at the end of the cantilever and is brought into a gentle contact with the target substrate (*e.g.*, a SiO_2/Si substrate). The translational motion of the substrate driven by a motor can result in a well-controlled relative rubbing between the gratings and the substrate. Such a gentle rubbing process between two different materials can generate triboelectric charge patterns on the target substrate without leading to any visible change to the substrate surface. **Fig. 1b** displays the photograph of the lab-made motorized rubbing tool. After the rubbing process, the substrate is loaded into a CVD tube for growing MoS_2 patterns, as illustrated by **Fig. 1c**. **Fig. 2a** displays the AFM topography image of a SiO_2 surface rubbed by periodic grating features, which does not show any visible rubbing-induced damage to the surface. **Fig. 2b** shows the AFM potential image captured from the same substrate area, which exhibits a high-contrast grating-like surface potential pattern, indicating the formation of a triboelectric charge pattern in the rubbed area. After the CVD process, few-layer MoS_2 patterns are selectively grown in the rubbed area and are consistent with the triboelectric charge pattern. **Fig. 2c** shows the SEM image of representative few-layer MoS_2 grating patterns selectively grown in the rubbed areas. Such RISS-grown MoS_2 ribbons can be used for making electronic devices such as transistors, biosensors, and 2D memristors. **Fig. 3** shows the pulse-programmed switching cycles of a 2D memristor made from a RISS-grown MoS_2 ribbon.

This work advanced the lithography/etching - free nanofabrication techniques for generating emerging layered semiconductor device patterns for making working electronic devices.

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* Email: xiaoganl@umich.edu

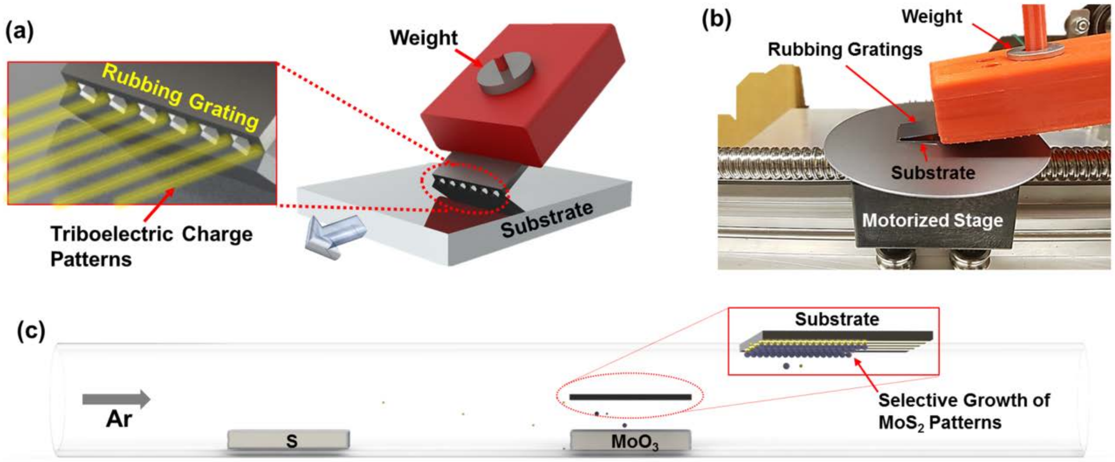

Fig. 1 Setup of the rubbing-induced site-selective growth (RISS) process: (a) illustration of the rubbing tool for generating triboelectric charge patterns on the target substrate; (b) photography of the rubbing tool; (c) site-selective growth of few-layer MoS_2 patterns in a CVD chamber.

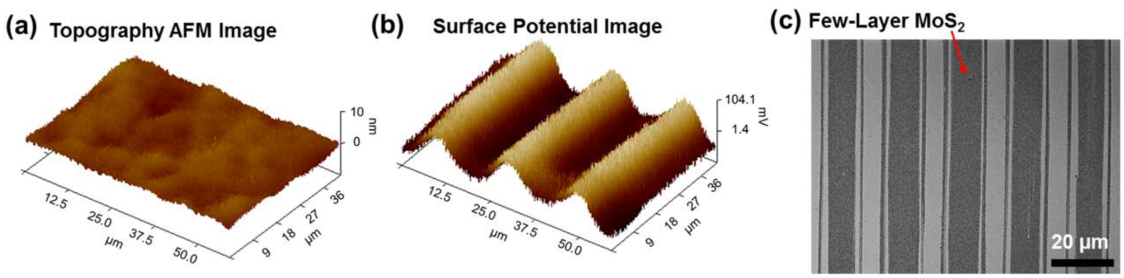

Fig. 2 (a) Topography AFM image of a SiO_2 surface rubbed by periodic grating features, which does not show any visible rubbing-induced damage to the surface; (b) surface potential image of the same surface area, which clearly shows a high-contrast grating-like potential pattern; (c) SEM image of few-layer MoS_2 grating features selectively grown in the rubbed areas.

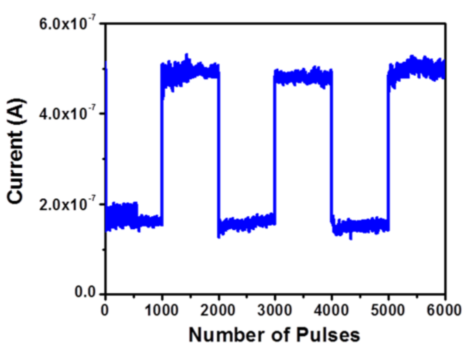

Fig. 3 Pulse-programmed switching cycles measured from a 2D memristor made from a RISS-grown few-layer MoS_2 ribbon.

* Email: xiaoganl@umich.edu