Lithography on 2D Materials for Stressor Film Deposition

CNF Project Number: 296721

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Primary Source(s) of Research Funding: The Gordon and Betty Moore Foundation's EpiQS Initiative (GBMF9062.01); Department of Energy, Basic Energy Sciences program Grant No. DE-SC0023905

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Primary CNF Tools Used: Heidelberg MLA 150 Maskless Aligner, SC4500 Evaporator, Zeiss Supra scanning electron microscope, Nabity Nanometer Pattern Generator System

Abstract:

To investigate the heterostrain-induced electronic properties in 2D materials, we fabricated stressor thin film Al2O3/SiO2/Al2O3 directly onto the target materials using lithographic patterning. Direct writing lithography tools were used to pattern the resist with stripes, followed by thin film deposition of stressors using e-beam evaporation. Subsequently, metal contacts were integrated for device characterization, revealing the effects of strain on the structural and electrical transport properties of MoS2.

Summary of Research:

Recent experimental advances in process-induced strain-engineering technique have enabled controlled strain application in 2D materials through lithographic patterning of stressor thin films [1], providing a versatile platform to engineer material properties. Here, utilizing the process- induced strain-engineering approach [2], we apply heterostrain to exfoliated MoS2 flakes by patterning evaporated thin film stressors, and fabricate biasing devices to characterize their resulting strain-induced electrical properties of MoS2.

The biasing devices were fabricated on conventional Si/SiO2 substrates. Figure 1 shows a cross- sectional schematic of the device design and a plan-view optical image of the device used for electrical transport measurements. First, the interdigitated electrode design with a 1 µm spacing, was patterned directly onto a Si/SiO2 substrate using photolithography with the MLA 150 direct writer. Cr/Au contacts were subsequently deposited using e-beam evaporation, followed by a lift-off process. Subsequently, the exfoliated MoS2 flakes were transferred onto the pre-patterned electrodes using a conventional polymer-assisted dry transfer technique. To introduce the local strain, the MLA 150 was used again to pattern a small stripe on top of the MoS2 flake (highlighted in red), where the Al2O3/SiO2/Al2O3 stressor films were deposited via e-beam evaporation. The draw-mode functionality of the MLA 150 facilitates the stressor patterning process without requiring any additional alignment steps, ensuring accurate overlay with the target flake region.

To investigate the structural effects of heterostrain at high resolution, we also fabricated samples on transmission electron microscopy (TEM) grids with freestanding membranes. Figure 2 shows optical images of the TEM grid overview and the fabrication process. Poly(methyl methacrylate) was used as the resist, and the patterning was conducted using e-beam lithography with the Nabity Nanometer Pattern Generator System on the Zeiss Supra scanning electron microscope. Manual alignment was employed to center the stripe patterns (~10 µm in width and spacing) onto the membrane region of the TEM grids. Following exposure, Al2O3/SiO2/Al2O3 stressor films were deposited via electron beam evaporation. The stripe-patterned stressor films were successfully deposited directly onto MoS2 flakes on the TEM grids, enabling subsequent structural characterization.

Next step, we investigated the local structural changes induced by heterostrain in MoS2 using scanning transmission electron microscopy (STEM). Figure 3 focus on a MoS2 flake under the patterned film stressor on the TEM grid. The white dotted line marks the boundary where the stressor film terminates. As shown in Fig. 3b and 3c, dislocations appear as bright lines in the low- angle annular dark-field STEM images due to the diffraction contrast. The observed diamond- shaped dislocation network in MoS2 likely originates from heterostrain-induced lateral displacement between layers. The strain transferred from the stressor film is primarily applied to the topmost few layers of MoS2, resulting in interlayer sliding and modified stacking configurations. This sliding induces a dislocation network that relieves the resulting lattice mismatch and reflect local structural relaxation mechanism in the system.

Conclusions and Future Steps:

DLS is a facile tool to characterize the emulsion condition of colloidal system. For emulsions with nanoparticles and multiple ingredients, it's a challenge to make ideally uniform nano-encapsulation environments. Concentration and temperature play critical roles and need to be modified systematically in the future.

References:

[1] Chenyun Yuan, Florian Kafer, and Christopher K. Ober. (2021). Polymer-Grafted Nanoparticles (PGNs) with Adjustable Graft-Density and Interparticle Hydrogen Bonding Interaction.

[2] Alicia Cintora, Florian Kafer, Chenyun Yuan, and Christopher K. Ober. (2021). Effect of monomer hydrophilicity on ARGET-ATRP kinetics in aqueous mini-emulsion polymerization.

[3] Roselynn Cordero, Ali Jawaid, Ming-Siao Hsiao, Zoe Lequeux, Richard A. Vaia, Christopher K. Ober, "Mini Monomer Encapsulated Emulsion Polymerization of PMMA in Aqueous ARGET ATRP", ACS Macro Letters, 7, 4, 459-463.

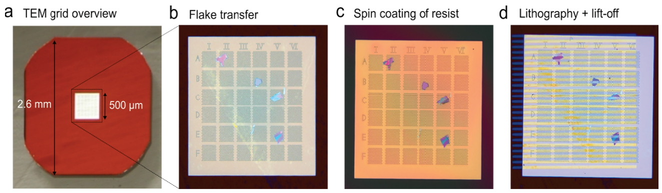

Figure 2: (a) Overview of the TEM grid with a 500 µm x 500 µm membrane where the material can be imaged with a TEM. (b-d) Zoomed-in images of the MoS2 flakes transferred onto a TEM grid, followed by the spin coating of the PMMA resist, then e-beam lithography patterning and lift-off, respectively. Stripes of the stressor film Al2O3 (10 nm)/SiO2 (30 nm)/Al2O3 (10 nm) are deposited on top of the MoS2.

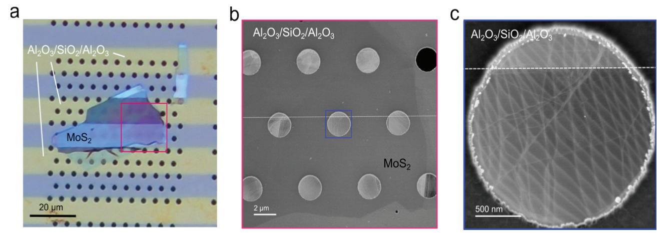

Figure 3: (a) An optical image showing a single MoS2 flake partially covered by a stressor film (yellow region on the TEM membrane). (b) Low magnification low-angle annular dark-field (LAADF) scanning transmission electron microscopy (STEM) image of MoS2 from the red box in (a). (c) LAADF STEM image of MoS2 over a single membrane hole from the blue box in (b), showing dislocations from the diffraction contrast.

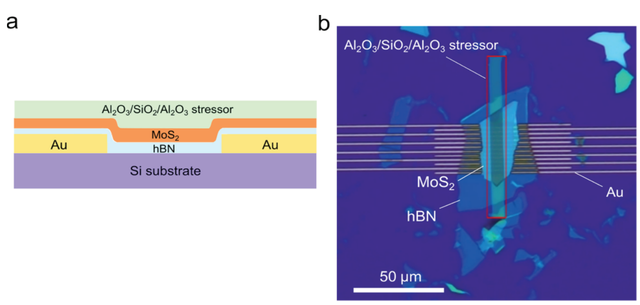

Figure 1: Figure 1. (a) Cross-sectional schematic of the device with stressor film. (b) Optical image of a biasing device fabricated for electrical transport measurements. The red outline shows where the stressor film was deposited. The MoS2 sits above the biasing electrodes and an insulating dielectric hBN layer.