Supporting Information

Out-of-Plane Electromechanical Coupling in Transition Metal Dichalcogenides

Christopher J. Brennan[1], *Kalhan Koul*[1], *Nanshu Lu*[1,2,3,4*], *Edward T. Yu*[1,4*].

[1]Department of Electrical and Computer Engineering, University of Texas at Austin, Austin, (TX), 78712 USA

[2]Center for Mechanics of Solids, Structures and Materials, Department of Aerospace Engineering and Engineering Mechanics, University of Texas at Austin, Austin, (TX), 78712 USA

[3]Department of Biomedical Engineering, University of Texas at Austin, Austin, (TX), 78712 USA

[4]Texas Materials Institute, University of Texas at Austin, Austin, (TX), 78712 USA

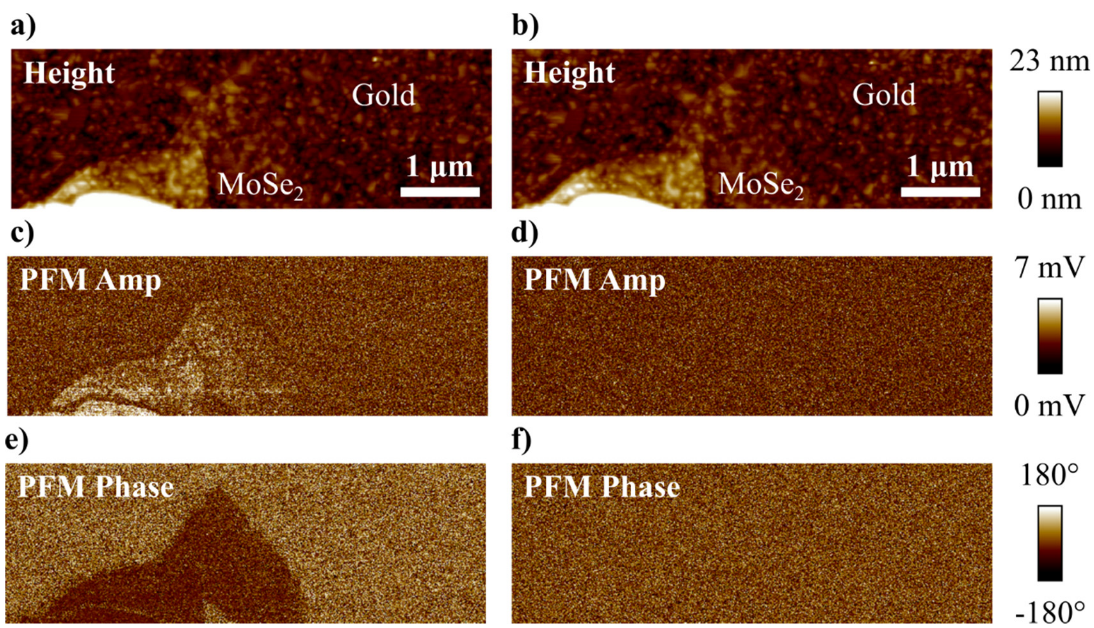
* Corresponding authors:

Edward T. Yu, ety@ece.utexas.edu, 512-232-5167, MER 1.206M, 10100 Burnet Rd. Bldg 160, Austin, TX 78758

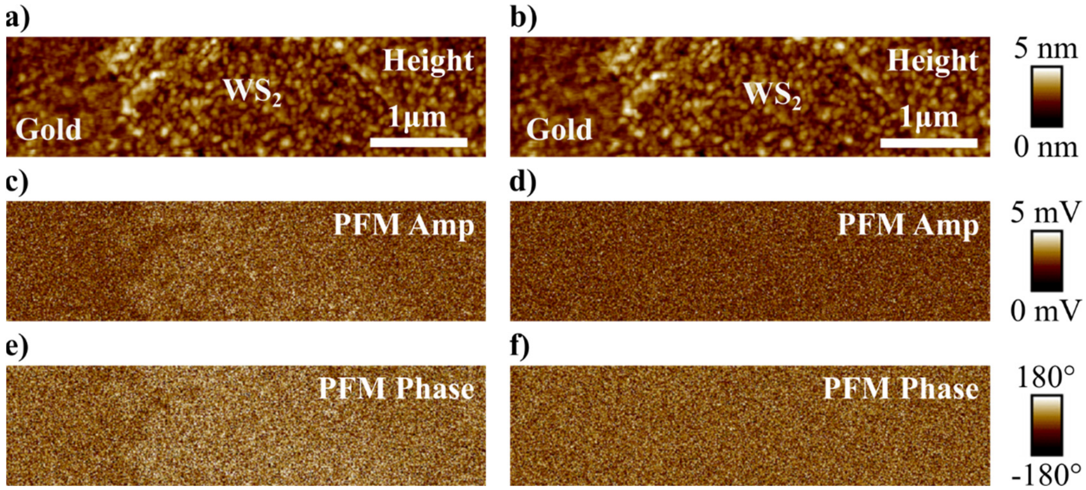
Nanshu Lu, nanshulu@utexas.edu, 512-471-4208, 210 E. 24th St, Austin, TX 78712

PFM Experimental Details

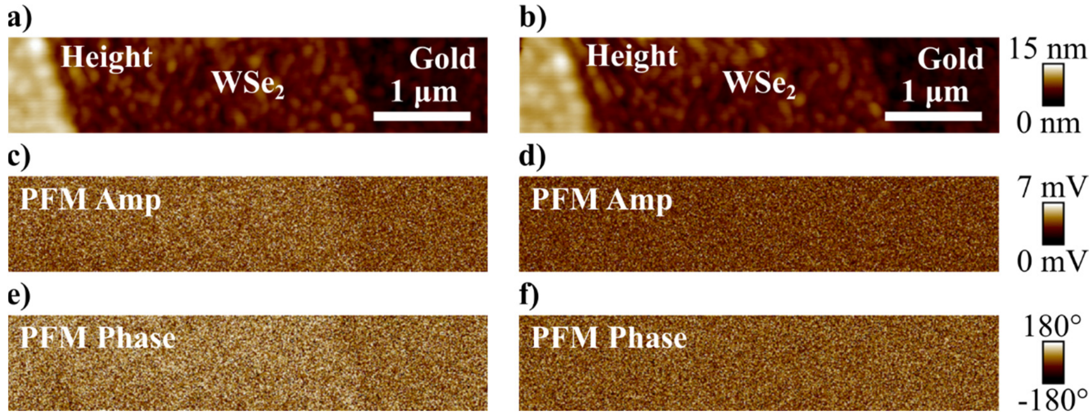
PFM measurements were done using a Bruker (formerly Veeco) Dimension Icon AFM. Conductive cobalt−chromium AFM cantilevers are used (Bruker MESP-RC-V2) for PFM measurements. Tapping mode AFM images were taken using etched silicon cantilevers (Bruker TESP). A PFM drive frequency of 60 kHz and a drive amplitude of 7 V were used in the presented measurements which had the drive voltage applied. When not applied to the sample, as in right half of the below figures, a 7 V amplitude and 60 kHz frequency signal is still input into the reference channel of PFM lock-in amplifier. A periodically-poled lithium niobite (PPLN) reference sample was previously measured to confirm the detection of oppositely polarized piezoelectric materials. Further details about the PFM experiment can be seen in our previous work "Out-of-Plane Electromechanical Response of Monolayer Molybdenum Disulfide Measured by Piezoresponse Force Microscopy" and it's Supporting Information in Nano Letters (DOI: 10.1021/acs.nanolett.7b02123).



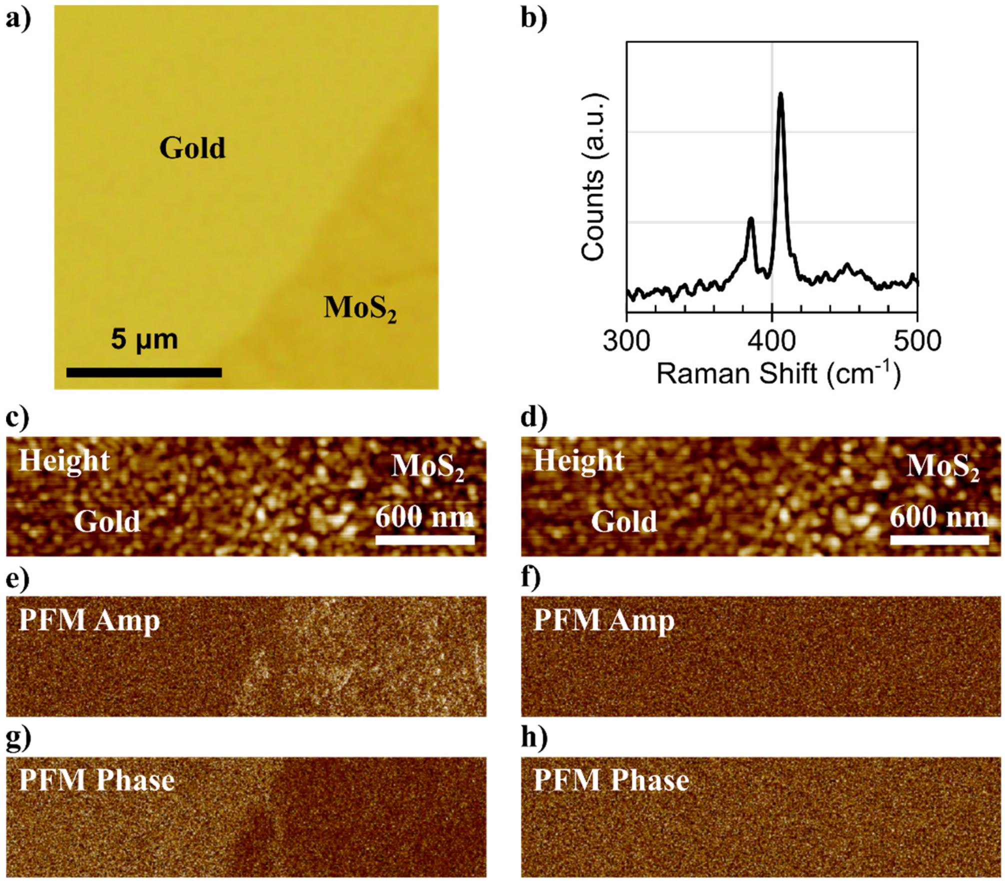
Supplemental Figure 1. PFM measurement of the same $MoSe_2$ sample as in Figure 2 where the height (a,b), PFM amplitude (c,d) and PFM phase (e,f) are shown for with the drive voltage applied (a,c,e) and not applied (b,d,f). Since there is no PFM contrast when the drive voltage is not applied, there are no scanning artifacts.



Supplemental Figure 2. PFM measurement of the same WS_2 sample as in Figure 2 where the height (a,b), PFM amplitude (c,d) and PFM phase (e,f) are shown for with the drive voltage applied (a,c,e) and not applied (b,d,f). Since there is no PFM contrast when the drive voltage is not applied, there are no scanning artifacts.



Supplemental Figure 3. PFM measurement of the same WSe_2 sample as in Figure 2 where the height (a,b), PFM amplitude (c,d) and PFM phase (e,f) are shown for with the drive voltage applied (a,c,e) and not applied (b,d,f). Since there is no PFM contrast when the drive voltage is not applied, there are no scanning artifacts.



Supplemental Figure 4. (a) Optical microscope image of CVD grown MoS_2 on gold. (b) Raman spectra of the CVD grown MoS_2 in (a) indicates monolayer MoS_2. PFM image on the MoS_2 on gold with the drive voltage on (c,e,g) and with the drive voltage off (d,f,h). The contrast in the PFM amplitude (e) and PFM phase (g) with the drive voltage applied indicates the presence electromechanical coupling. The lack of contrast in the PFM amplitude (f) and PFM phase (h) when the drive voltage not applied indicates no scanning artifacts.