Supporting Information

Enhanced Electrical Properties of Lithography-Free Fabricated MoS_2 Field Effect Transistors with Chromium Contacts

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Supplementary Figures

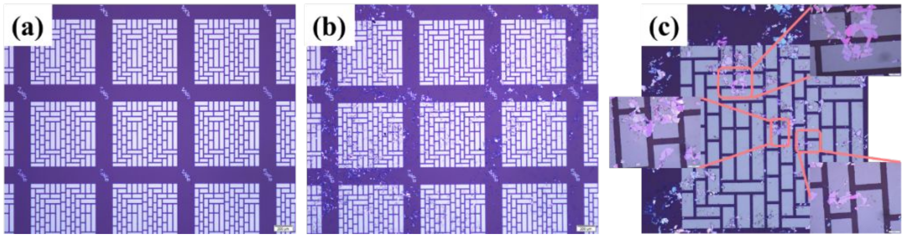

Figure S1. The optical microscope image of maze-like source/drain electrodes. (a) before and (b) after MoS_2 crystals mechanically exfoliated and MoS_2 flakes transferred. (c) The optical microscope image of maze-like source/drain electrodes with MoS_2 flakes at higher magnification, the selected devices are marked with orange boxes. Here, the substrate is Si/SiO_2·and the metal of source/drain electrodes is 20 nm-chromium (Cr), and the space between electrodes are set to be 5 or 10 μm. The flakes are exfoliated and the probability of single channel/multiple channels being formed on the same source drain electrode pair is quite high. It is noted that the multiple channels formed on the same source/drain electrode pair can result in reduced yield of final devices which should be carefully examined.

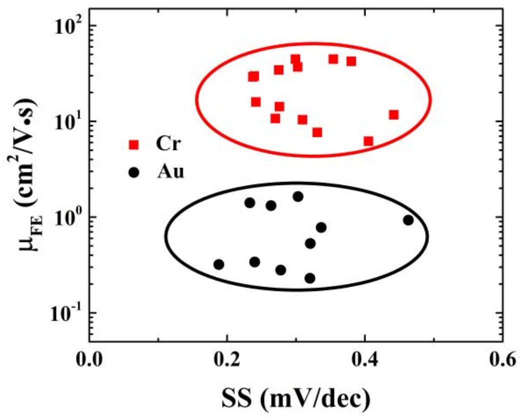

Figure S2. Statistics of Cr-MoS_2 FETs and Au-MoS_2 FETs in terms μ_{FE} and SS_{min}, demonstrating a beneficial trend in device performance as a result of Cr source/drain electrodes for a total of 10+ devices. The electrical parameters of multilayer MoS_2 FETs are extracted at V_{DS} = 50 mV.

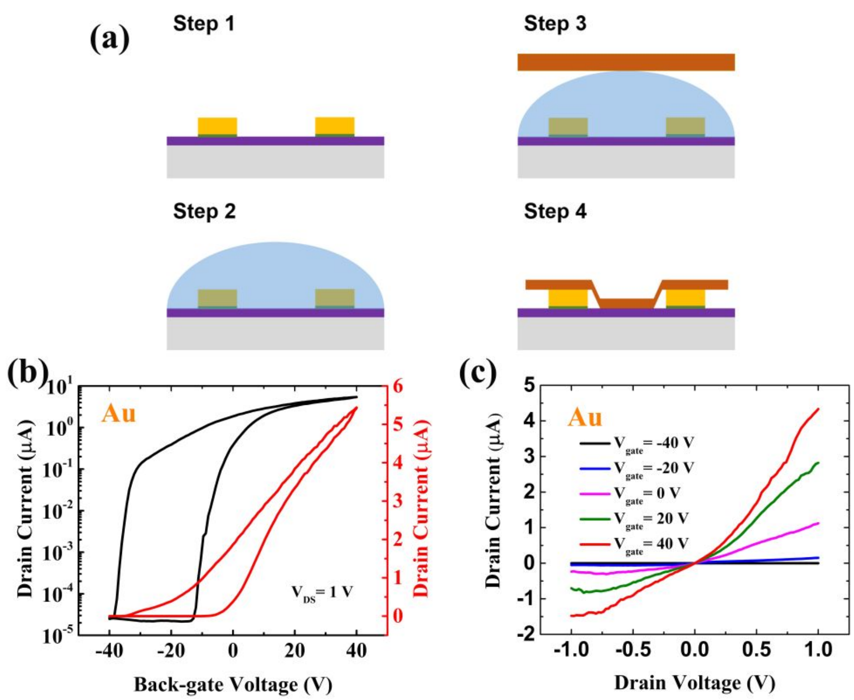

Figure S3. Fabrication of Au-MoS_2 FETs using liquid assisted exfoliation method and electrical performance of a typical Au-MoS_2 FET. (a) The control experiment flow of using solution to create more intimate contact between multilayer MoS_2 and Au electrodes. Step 1, Prepare the substate; Step 2, Drop with a drop of solution (mixture of alcohol and deionized water, the ratio is 1:1) on the substrate, then transferring the MoS_2 flake onto the moist substrate (Step 3); Step 4, Find the target multilayer MoS_2 FET. The multilayer MoS_2 FET is characterized after the solution is completely volatilized. (b)Transfer curves of Au-MoS_2 FET using solution assisted exfoliation. (c) Output curves of Au-MoS_2 FET using solution assisted exfoliation.

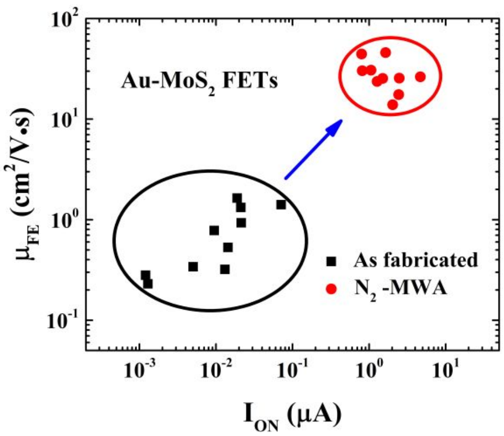

Figure S4. Statistics of Au-MoS_2 FETs before and after MWA in terms μ_{FE} and I_{ON}, demonstrating a beneficial trend in device performance as a result of MWA for a total of 10 devices. The electrical parameters of multilayer MoS_2 FETs are extracted at V_{DS} = 50 mV.

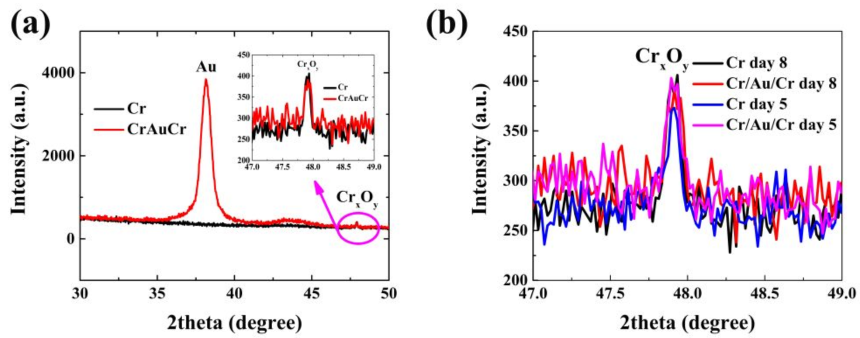

Figure S5. XRD image of Cr and Cr/Au/Cr films on the eighth day. As shown in Figure S6, the Cr_xO_y peak intensity of the two films was basically at the same level, and was consistent with the peak intensity of Cr/Au/Cr film on the fifth day. Therefore, it was inferred that Cr metal reached stable oxidation level after 8 days.

Supplementary Notes

Note 1: Extraction of intrinsic mobility and contact resistance.

Here, we used Y-function method to evaluate the electrical parameters of the fabricated multilayer MoS_2 FETs, and it has been proven that Y-function is a reliable method of extracting intrinsic mobility and contact resistance in MoS_2 FETs.[1-2]

The Y-function method is based on the analysis of the transfer characteristics (I_{DS}-V_{GS}) in the linear region. Considering that V_{GS}-V_{TH} >> V_{DS} under strong inversion at low V_{DS}, the I_{DS}-V_{GS} equation in the linear region can be simply expressed as[1]

$$\mathrm{I_{DS}} = C_{OX}\frac{W}{L}(V_{GS}-V_{TH})V_{DS}\left(\frac{\mu_0}{1+\theta(\mathrm{V_{GS}}-\mathrm{V_{TH}})}\right) \quad \text{(S1)}$$

Where C_{OX} is the gate capacitance, W and L are the FET width and length, respectively. V_{TH} is the threshold voltage, V_{GS} and V_{DS} are the gate and drain voltages, respectively. The mobility degradation factor, $\theta = \theta_0 + \mu_0 C_{OX}\frac{W}{L}R_C$, is included to better depict the realistic device performance. μ_0 and R_C are the intrinsic mobility and contact resistance, respectively.

Assume that R_C is not V_{GS} dependent, Y-function can be expressed as

$$\mathrm{Y} = \frac{I_{\mathrm{DS}}}{g_m} = \left(C_{OX}\frac{W}{L}V_{DS}\mu_0\right)^{0.5}(V_{GS}-V_{TH}) \quad \text{(S2)}$$

Where g_m is the transconductance defined as dI_{DS}/dV_{GS}. The Y-function curve can be used to extract the V_{TH} (intercept), and μ_0 (slope) of the MoS_2 FET.

Using equation (1), θ can be calculated by the known V_{TH} and μ_0. As demonstrated by Na,[2] the θ_0 component can be ignored in multilayer MoS_2 FET. Then the R_C can be calculated by the known θ and μ_0.

Reference

(1) Chang, H. Y.; Zhu, W. N.; Akinwande, D. On the Mobility and Contact Resistance Evaluation for Transistors Based on MoS_2 or Two-Dimensional Semiconducting Atomic Crystals. *Appl. Phys. Lett.* **2014**, *104*, 113504.

(2) Na, J.; Shin, M.; Joo, M. K.; Huh, J.; Kim, Y. J.; Choi, H. J.; Shim, J. H.; Kim, G. T. Separation of Interlayer Resistance in Multilayer MoS_2 Field-Effect Transistors. *Appl. Phys. Lett.* **2014**, *104*, 233502.