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Oxide-mediated self-limiting recovery of field effect mobility in plasma-treated MoS_2

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MoS_2-plasma interaction in the literature

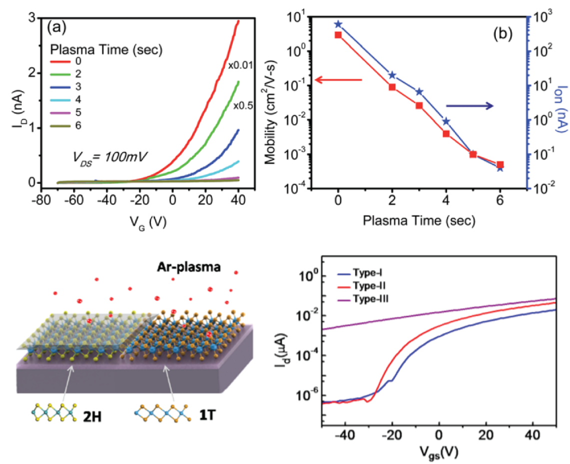
O_2 plasma

- Oxygen forms MoO_3 through sulfur-replacing reaction.
- This hampers device conductivity and causes p-type doping.

Ar plasma

- Argon won't react chemically, but will make sulfur vacancies.
- It has been found to cause 2H $\rightarrow$ 1T polytype shift by displacing top sulfuric layer.

For our experiment we used a 1:3 mixture of O_2:Ar gas.



Pure O_2 plasma

Pure Ar plasma

Figure 1: *Top panels*: Islam, M. et al. Nanoscale 6.17 (2014): 10033-10039.
Bottom panels: Zhu, J. et al. Journal of the American Chemical Society 139.30 (2017): 10216-10219.

Electrical testing with increasing plasma exposure

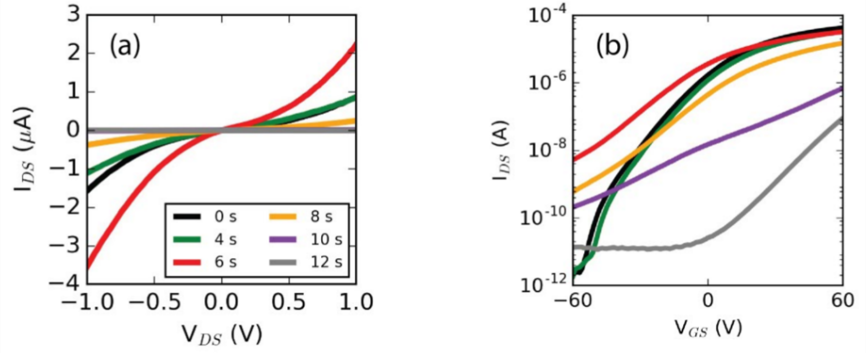


Figure 2: (a) IV sweeps at no gate bias. (b) Gate sweeps at drain-source bias of 1V.

Mobility boost observed at 6 seconds

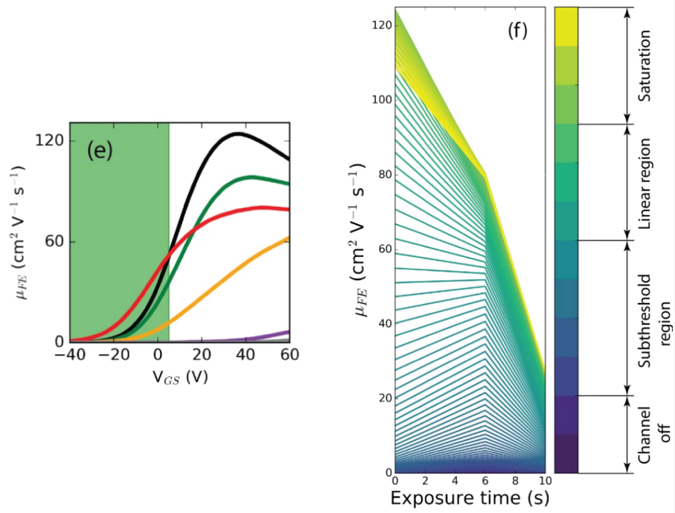


Figure 3: **(e)** Mobility across the whole gate bias range. **(f)** μ_{FE} extracted over time at each gate bias.

AFM & SEM indicate material change to flake surface

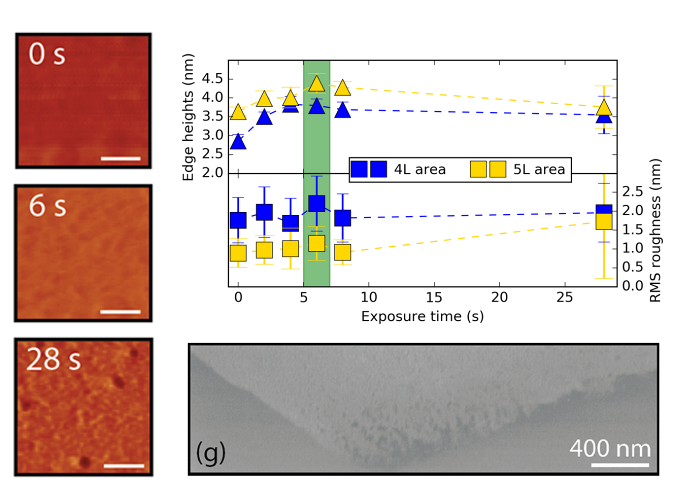


Figure 4: Flake increases in height with plasma treatment; patches of oxide form on the surface. Scale bar in AFM maps is 200 nm.

Spectroscopies confirm presence of MoO_3

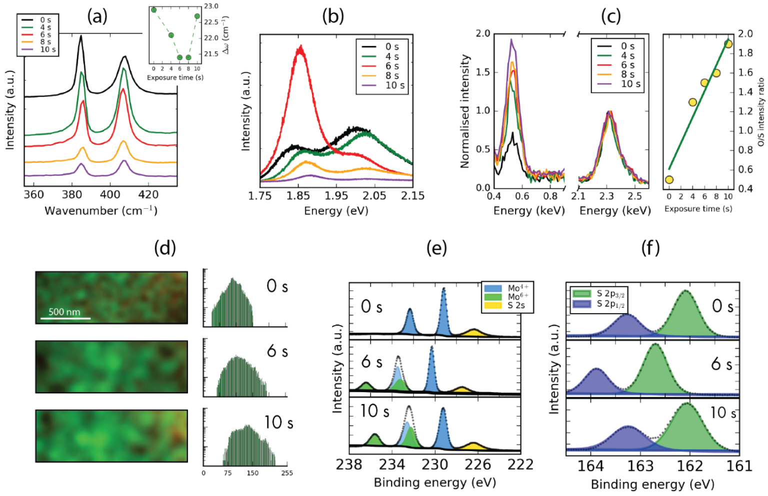


Figure 5: **(a)** Raman and **(b)** PL suggest decoupling of top layer. **(c)-(d)** EDX mapping shows increased oxygen content relative to sulfur. **(e)-(f)** XPS confirms MoO_3 presence on the surface and removal of sulfur.

Surface damage surveyed by TEM

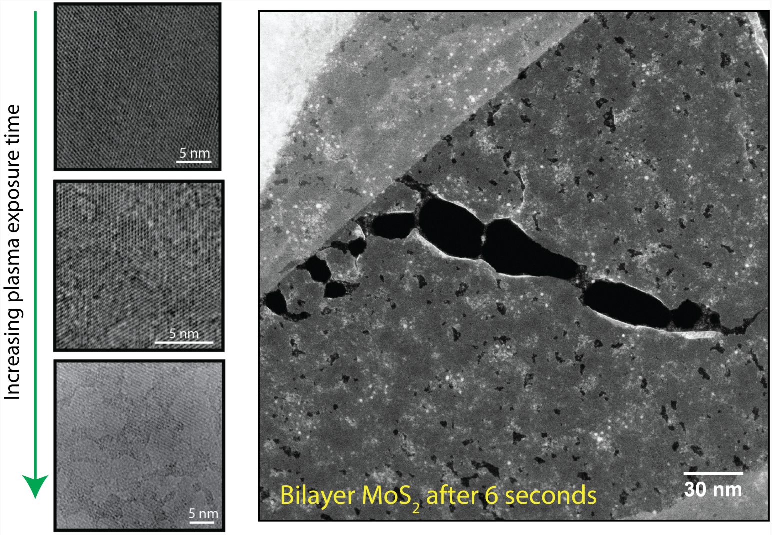


Figure 6: *(left)* HRTEM, *(right)* HAADF ACSTEM.

Size distribution of oxide-mediated etched pits at 6 seconds

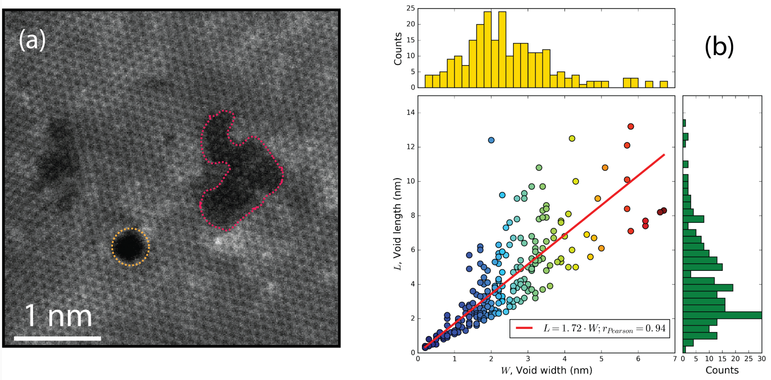


Figure 7: (a) Perforation circled in orange, pit circled in red. **(b)** Lateral void dimensions increase isotropically with time.

Oxides desorb from pits over time at UHV

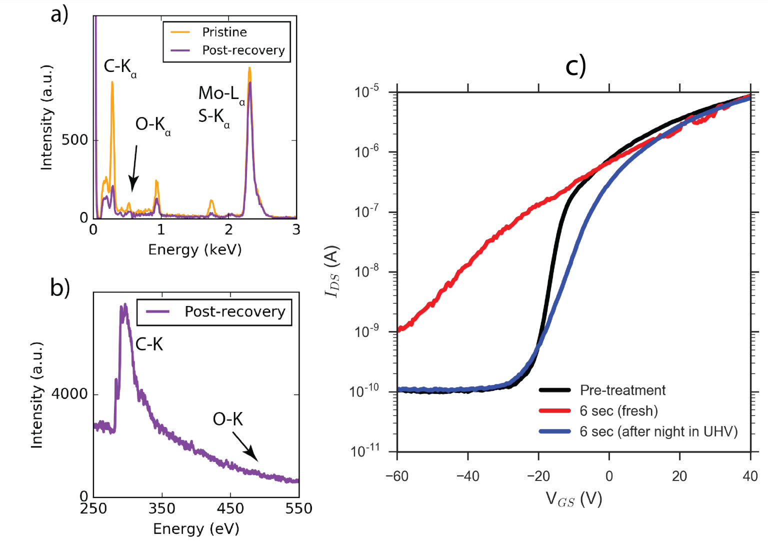


Figure 8: **(a)** EDX in ACSTEM. **(b)** EELS in ACSTEM. **(c)** Electrical testing overnight.

Proposed model of mobility enhancement

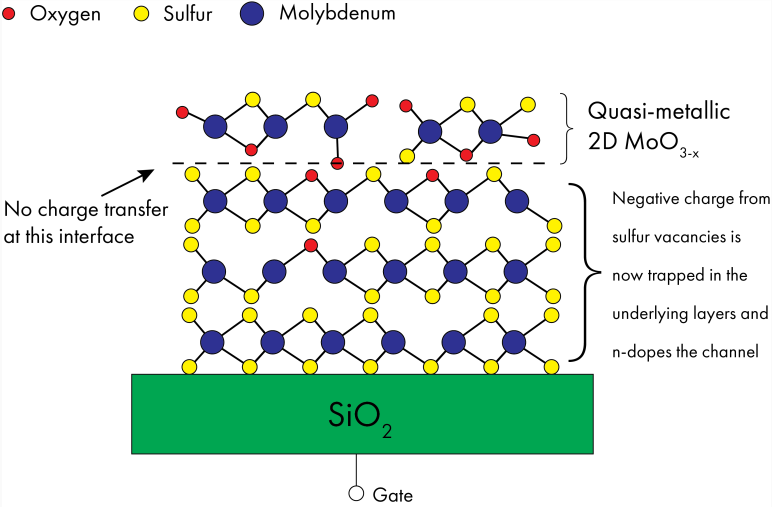


Figure 9: Cartoon of oxide-capped 4L MoS_2 device.

Conclusions:

2D MoO_{3-x} phase forms at 6 seconds on the top layer, electrically shields the MoS_2 channel and enhances conductivity.

It is qualitatively different from the insulating MoO_3 phase which forms at longer treatment times (volatility, electrical properties, etc.)

Its existence may be exploited in future van der Waals devices.

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