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

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Plasma functionalisation of MoS_2

O_2 plasma

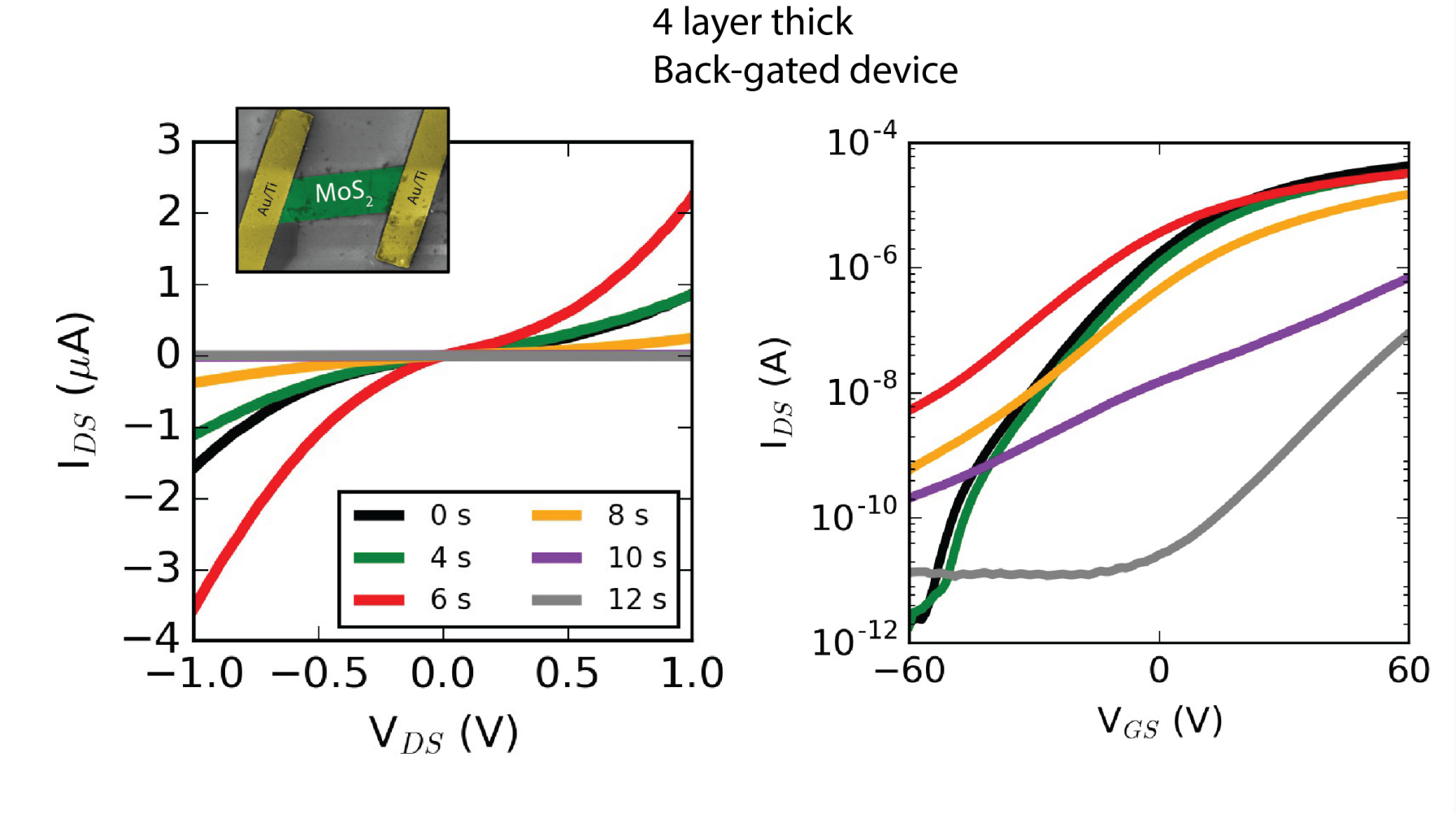
- Oxygen forms MoO_3 through sulfur-replacing reaction.
- This hampers device conductivity and causes p-type doping.

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.

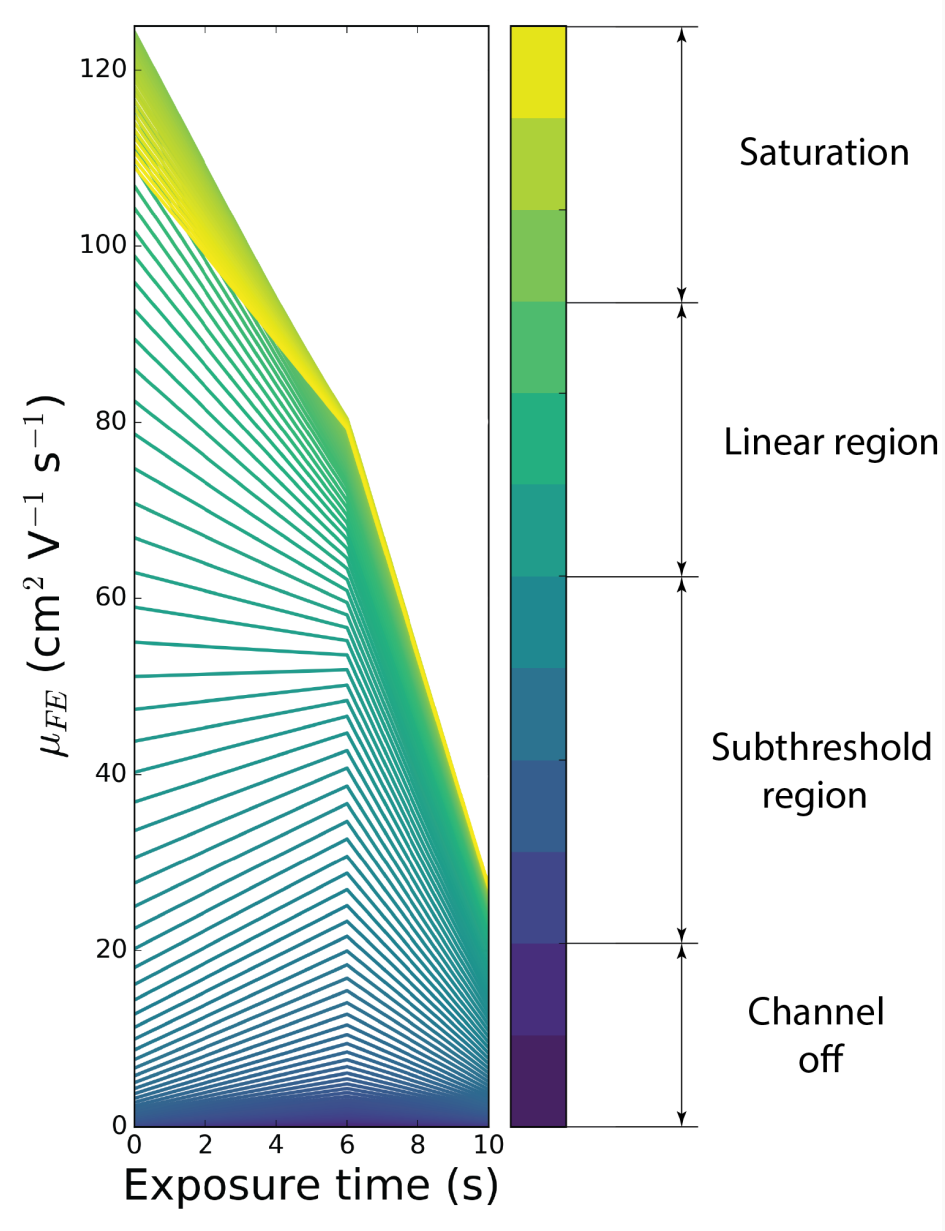
For our experiment we used a **1:3 mixture of O_2:Ar gas.**

Electrical testing with increasing plasma exposure

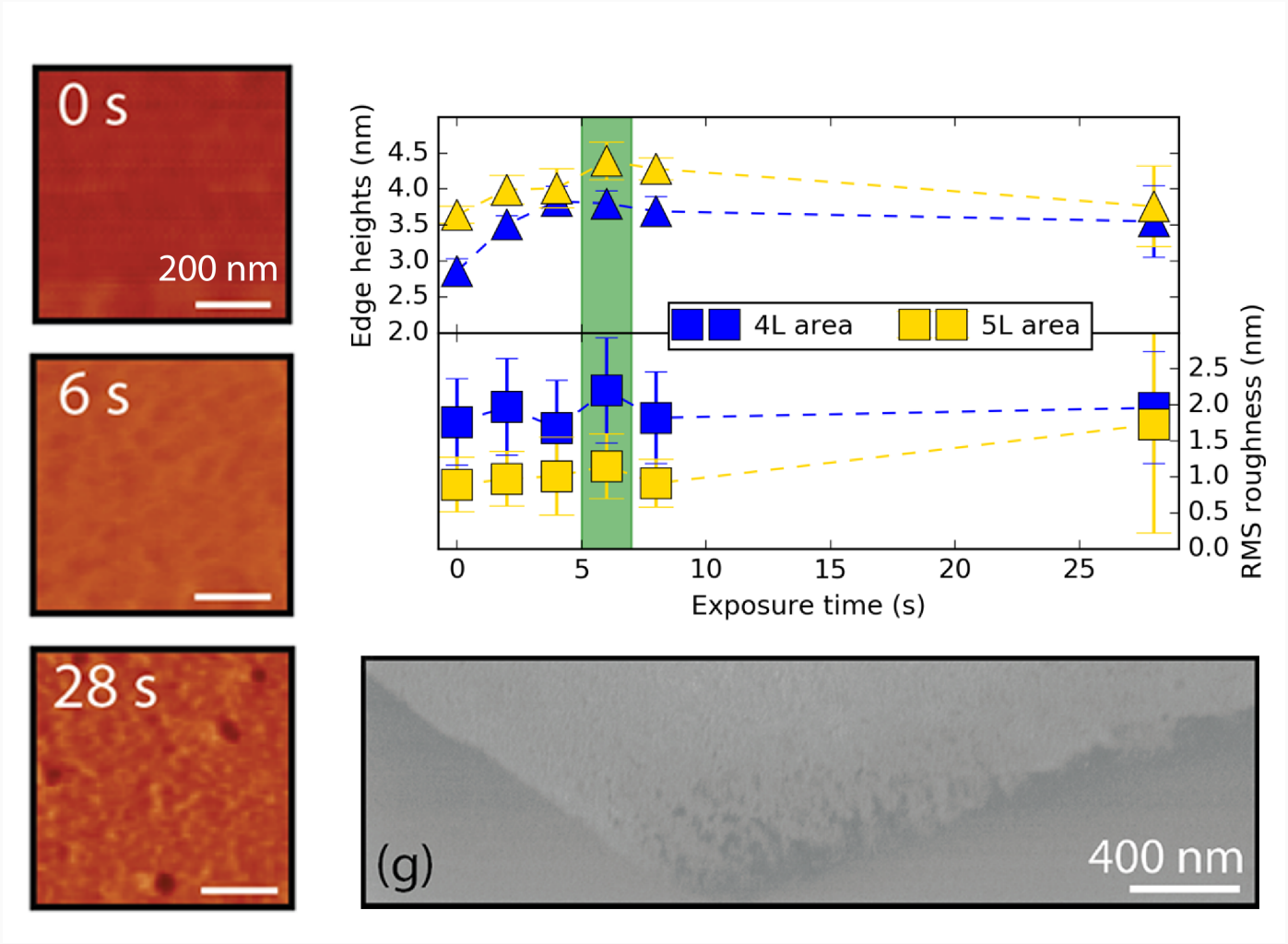


- Conductance increase at 6 seconds.
- Large V_{th} shift and subthreshold swing increase after 6 seconds.

Mobility boost observed at 6 seconds

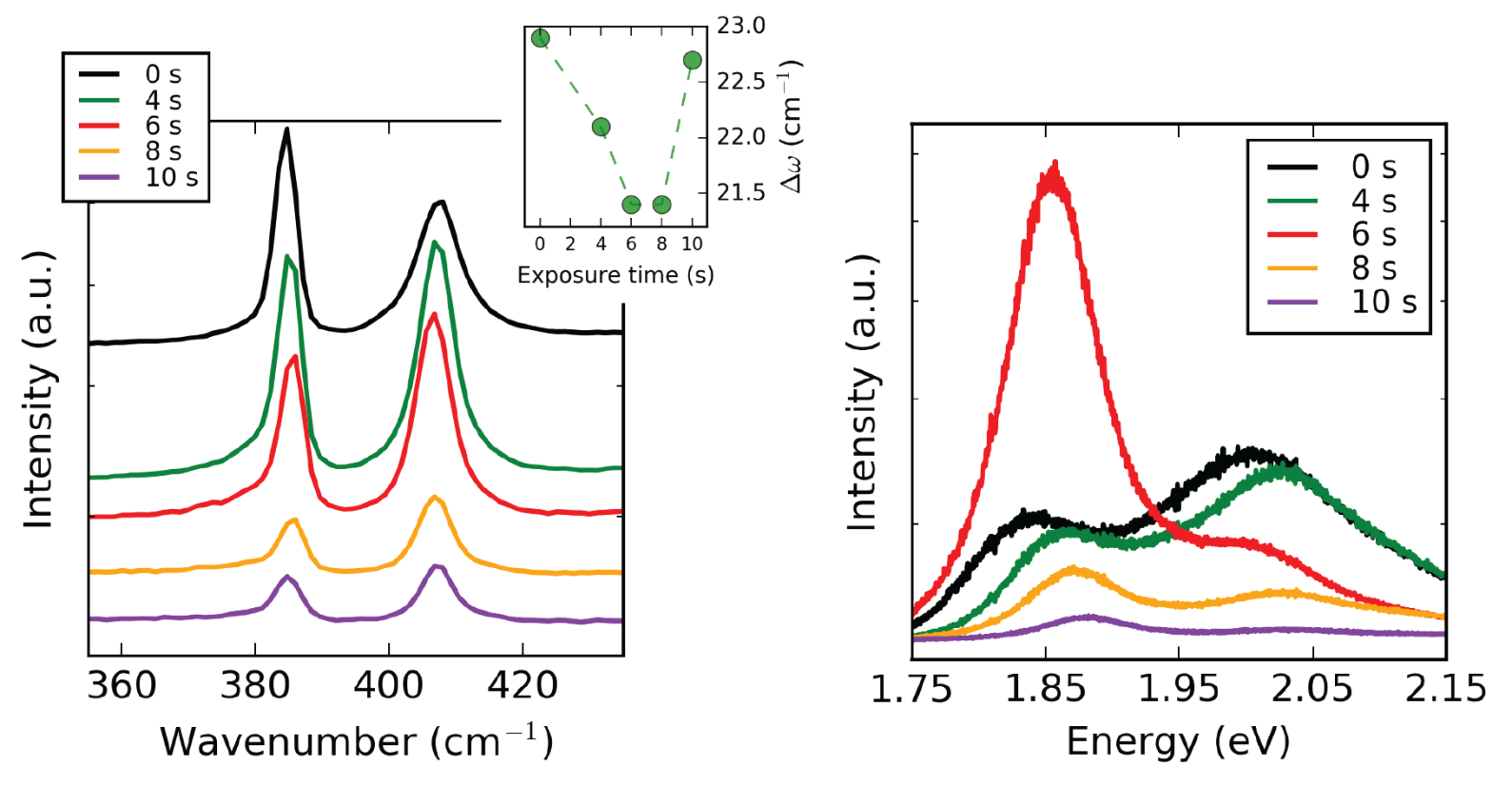


AFM & SEM indicate material change to flake surface



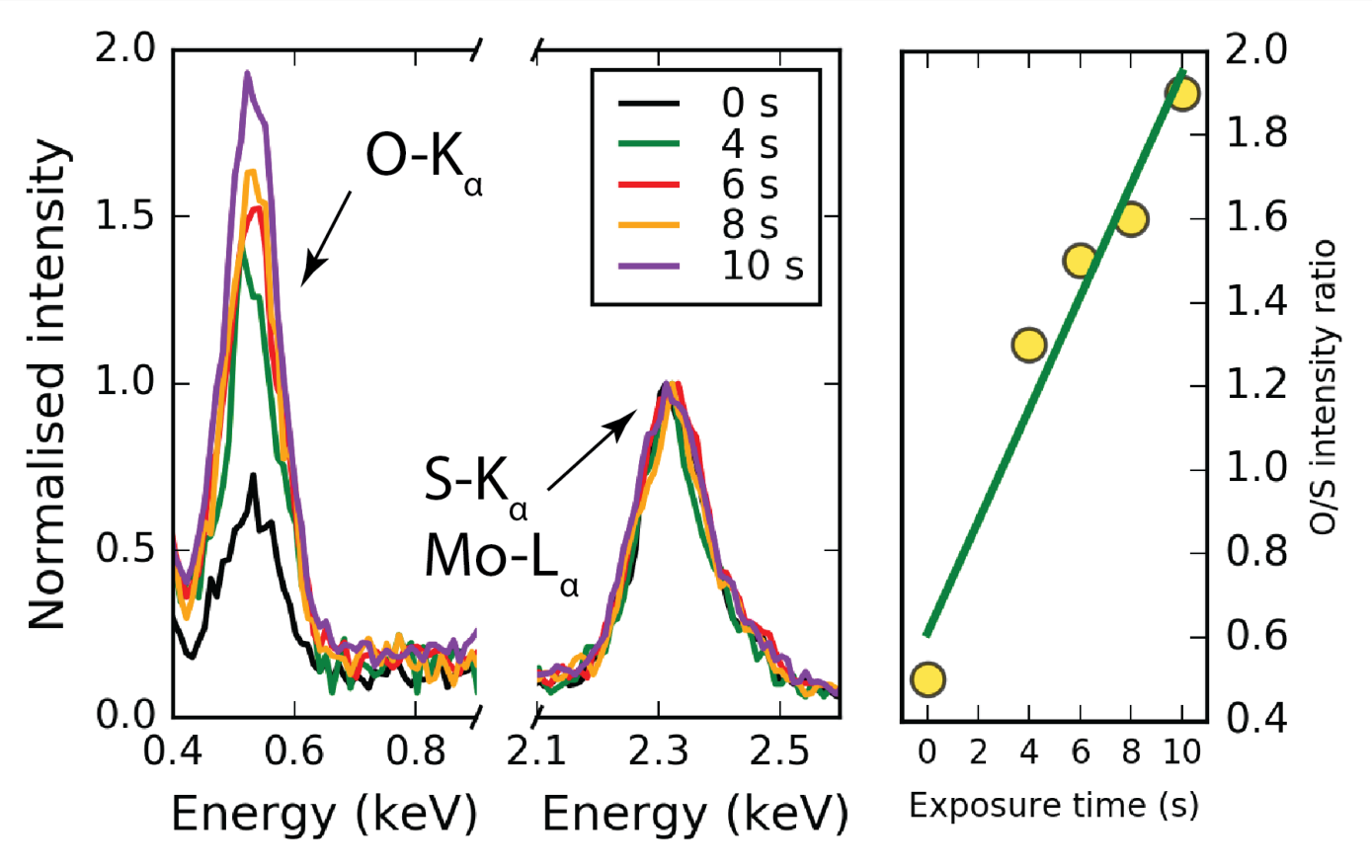
- Material contrast in phase AFM and SEM.
- Flake height increases while surface roughness stays constant.

Raman & PL of 4L flake



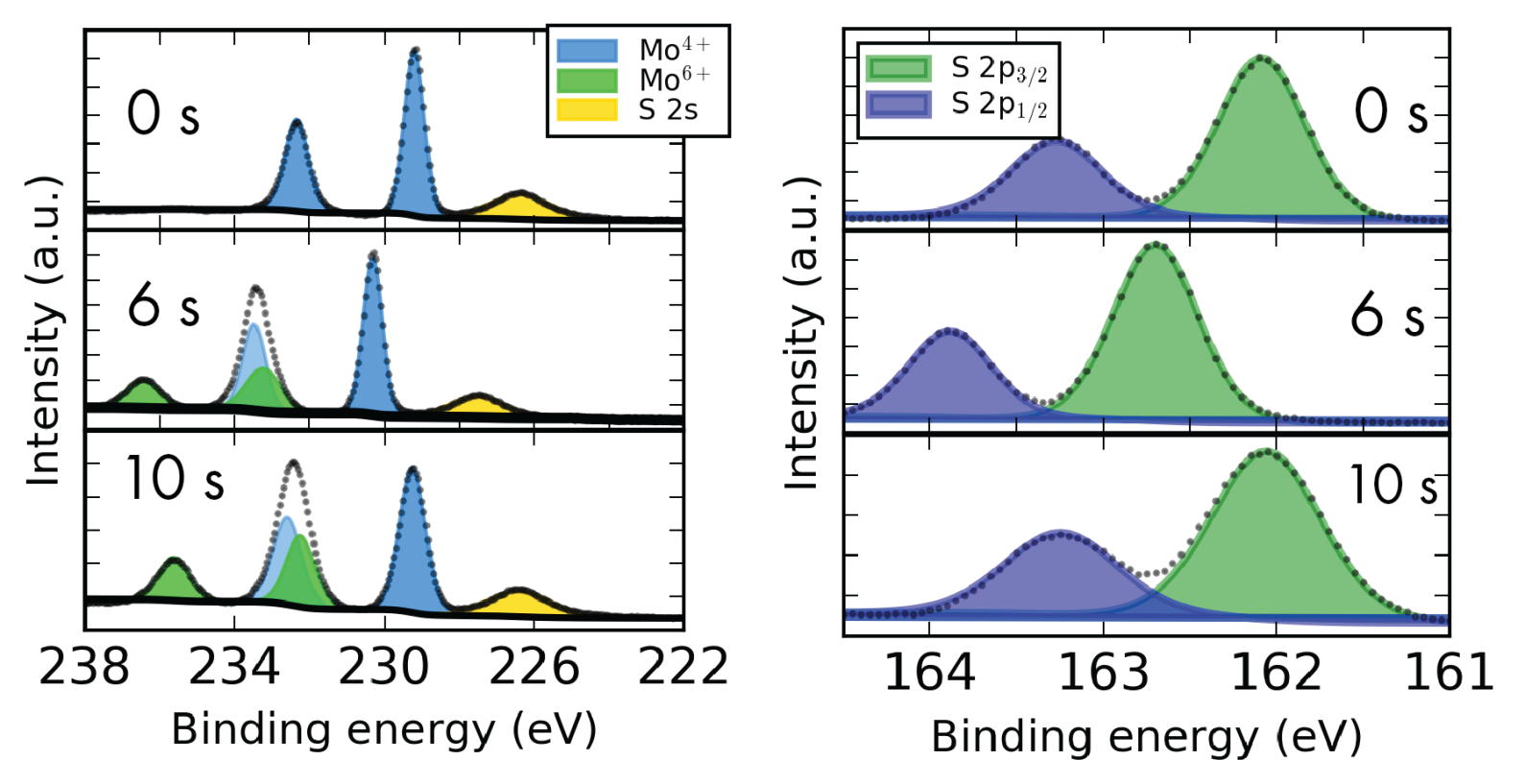
- Quenching of both Raman modes.
- Indirect $\rightarrow$ direct PL emission shift after 6 seconds.

EDX mapping of freshly treated 4L sample



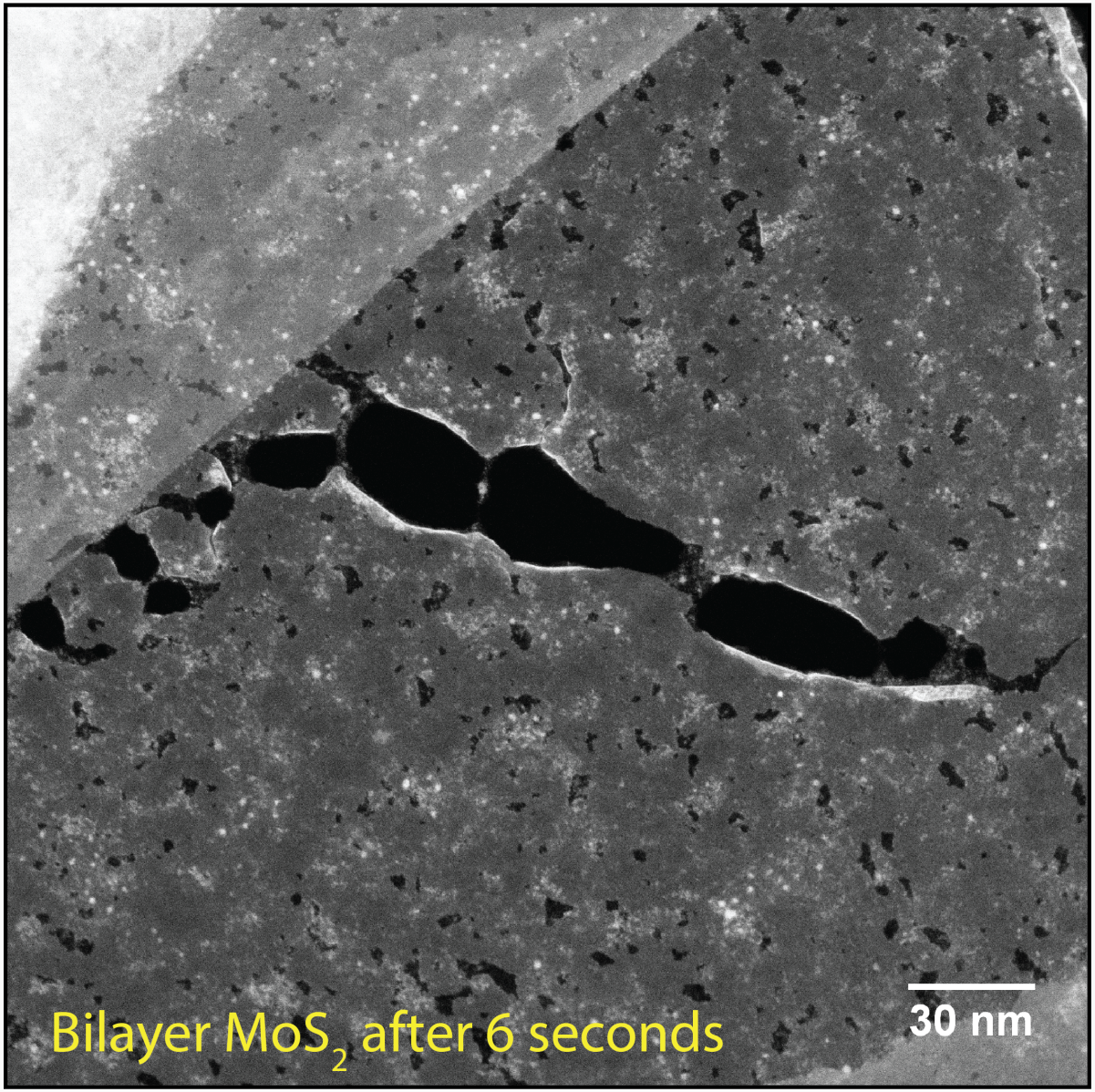
- Oxygen content increases relative to sulfur.

XPS confirms presence of MoO_3

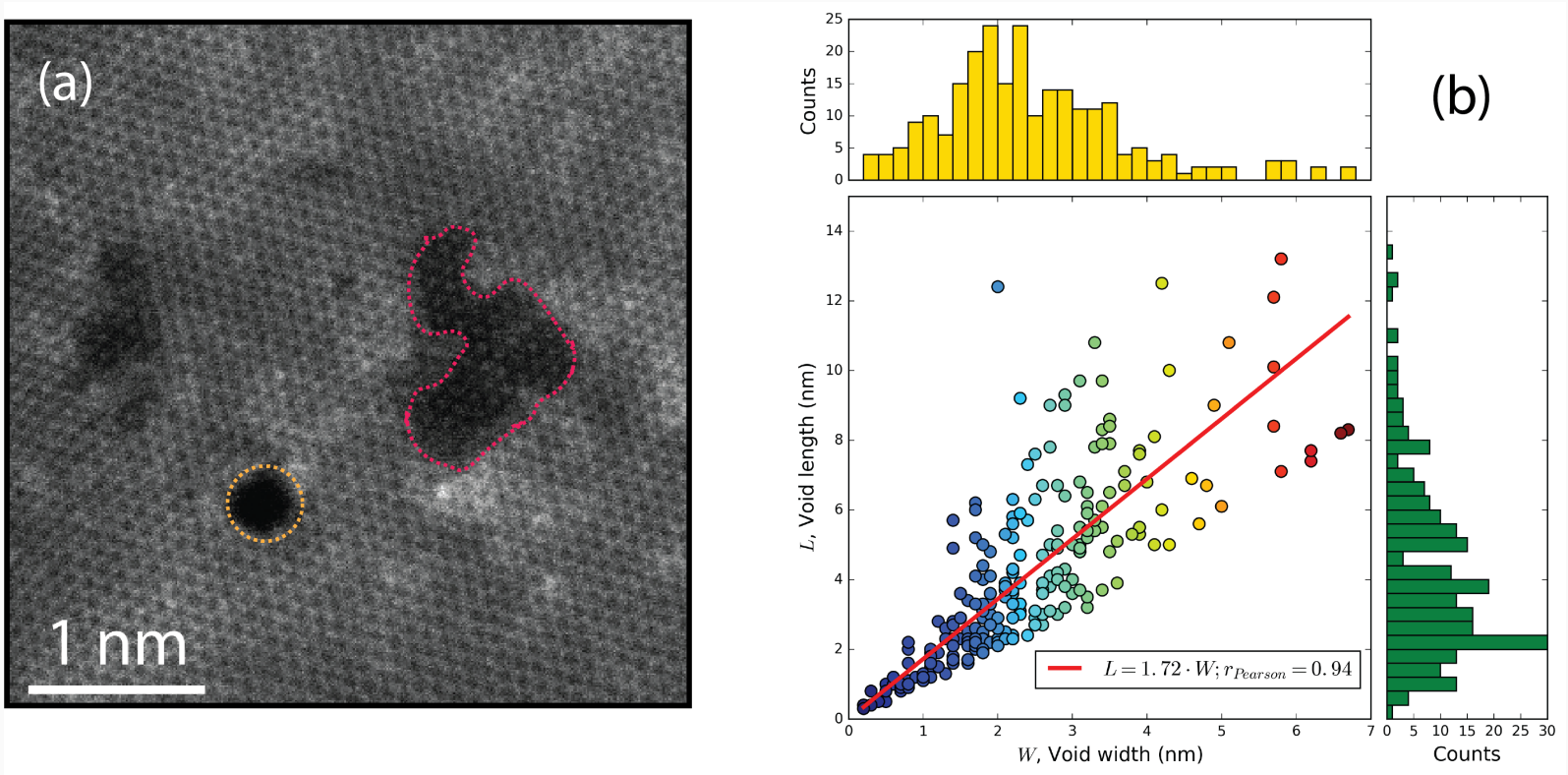


- Rise in MoO_3 concentration & improved stoichiometry.
- Large shift to higher binding energies indicative of n-type doping.

Surface damage surveyed by TEM

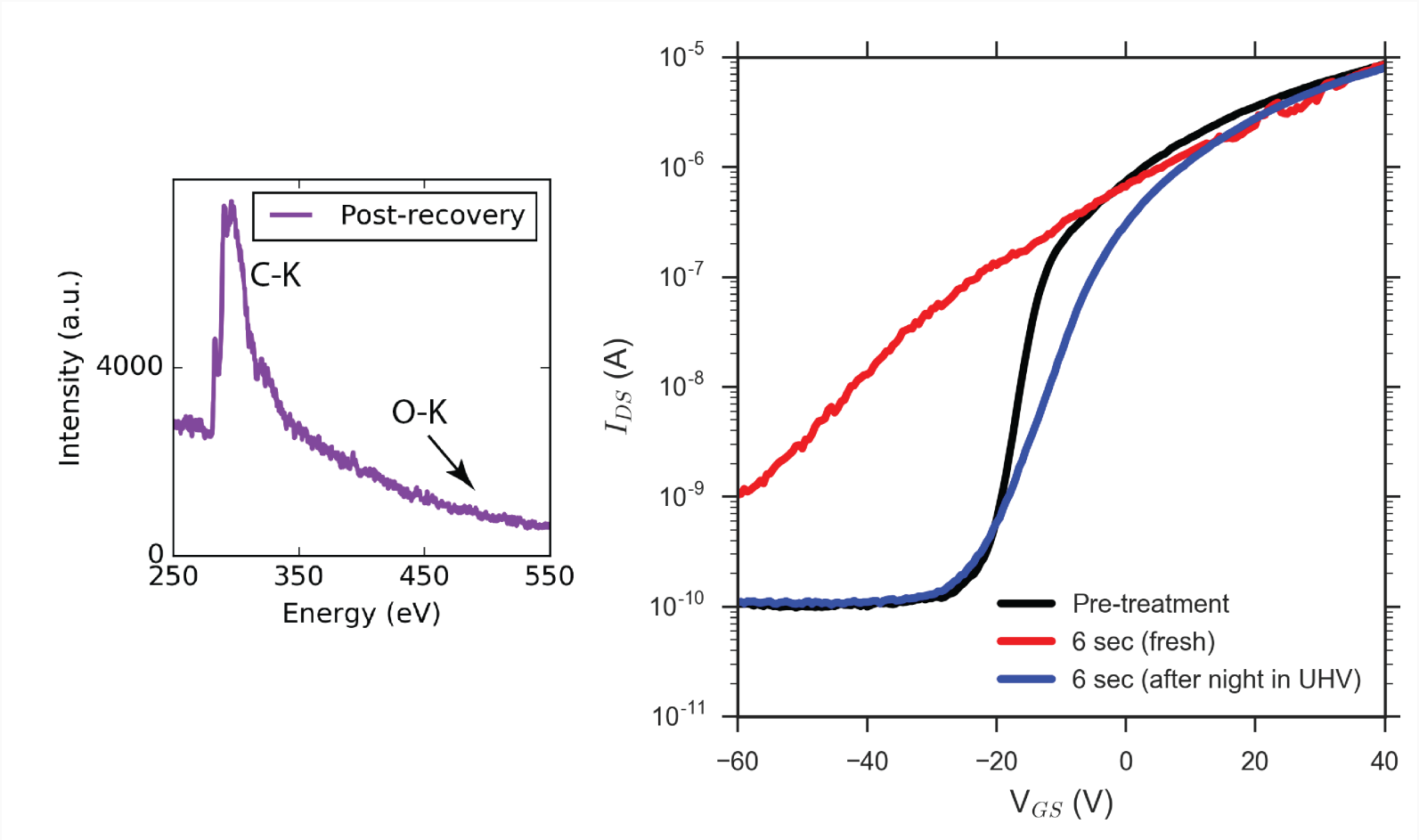


Size distribution of oxide-mediated etched pits at 6 seconds



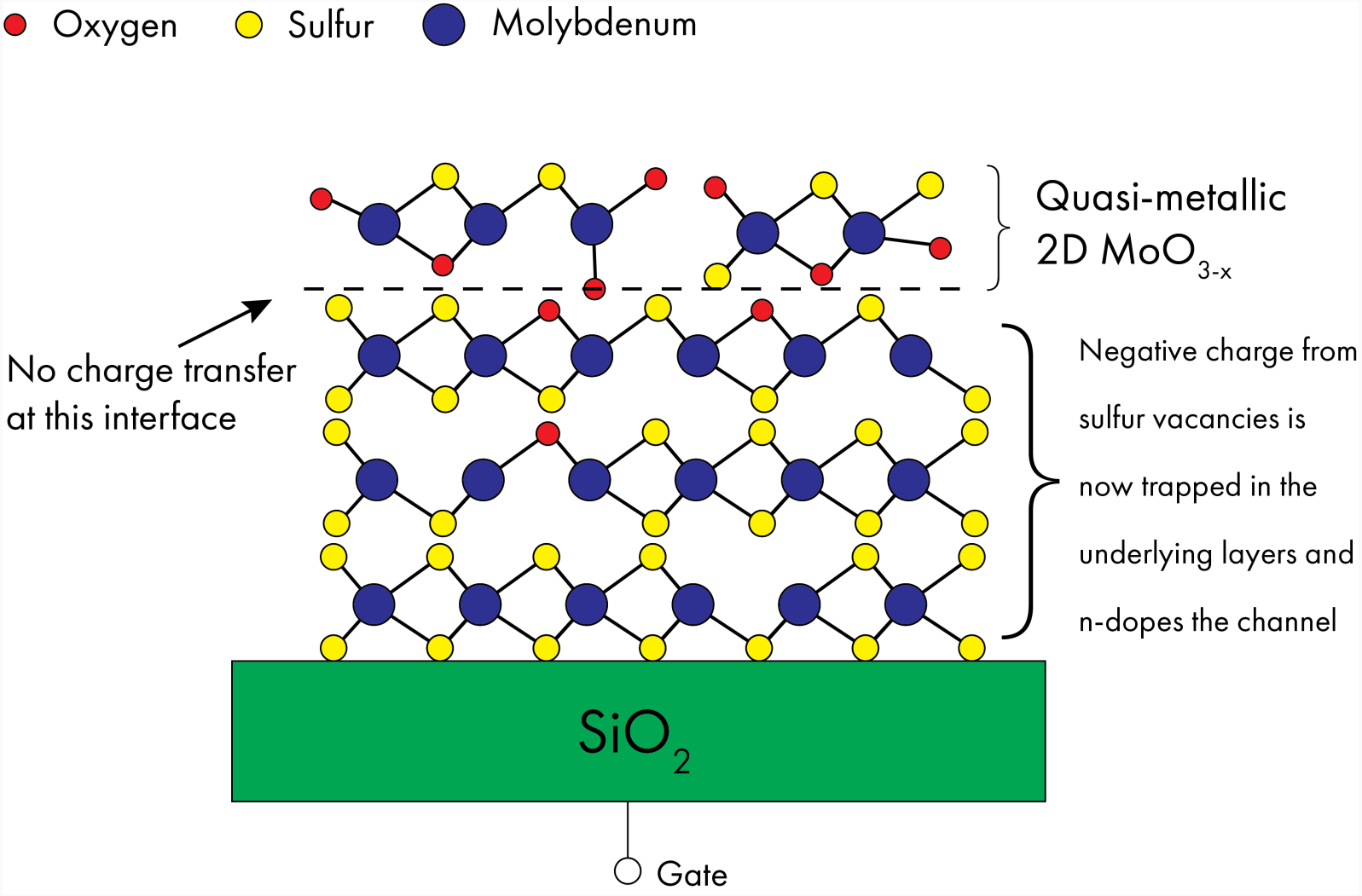
- Perforations and pits form on the surface.
- They increase in area with increasing plasma time.

Oxides desorb from pits over time at UHV



- EELS & EDX mapping show no oxygen.
- Mobility boost is reversed after 12 hours in UHV.

Proposed model of mobility enhancement



Conclusions:

2D MoO_{3-x} phase forms at 6 seconds on the top layer.

It enhances MoS_2 FET performance by screening charged scattering centres.

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

Mixed plasma treatment is a promising avenue for device functionalisation.

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Resistive network simulation