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Non-volatile Resistive Switching in Nanocrystalline MoS_2 with Vertically Aligned Layers Enabled by Mobile Ions

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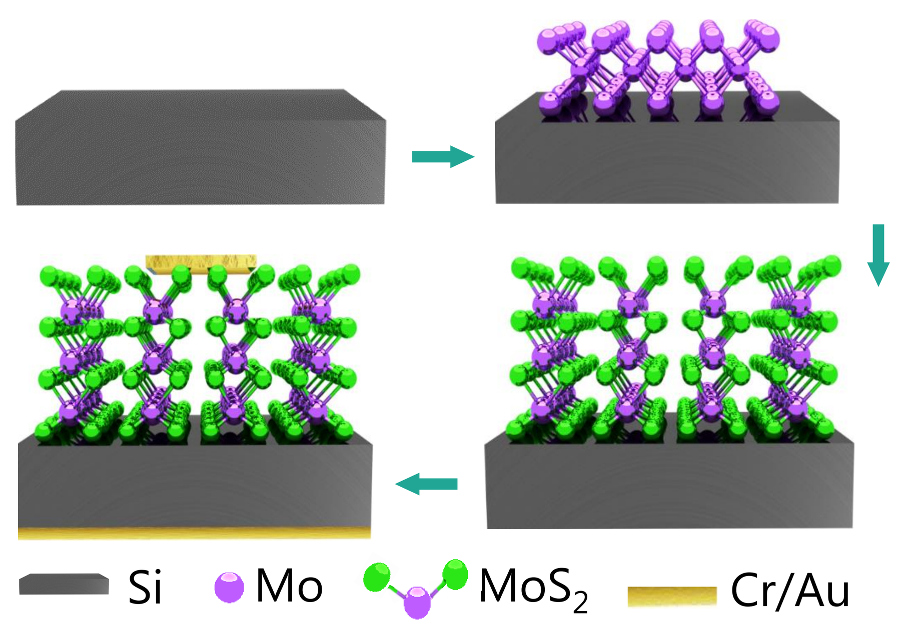
ABSTRACT

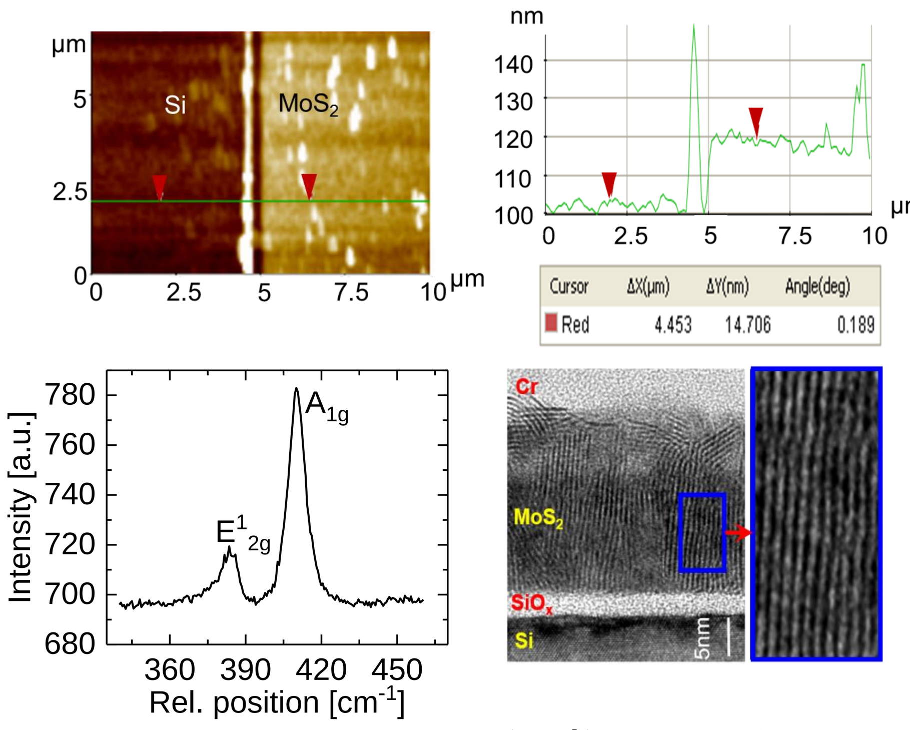
Two-dimensional (2D) layered materials are capable of providing bio-realistic ionic interactions that are needed for energy-efficient artificial neural networks that can potentially emulate the functioning of the human brain[1]. Molybdenum disulfide (MoS_2) is a layered 2D transition metal dichalcogenide (TMD) material which is gaining considerable attention recently for exhibiting a memristive effect. However, the mechanism and origin of the effect still remains unclear. This work provides experimental demonstrations on the presence and origin of a nonvolatile, bipolar and forming-free resistive switching (RS) in nanocrystalline MoS_2 with vertically aligned layers. DC switching tests show a stable endurance for at least 140 DC switching cycles and state-retention for at least 2500 s. Controlled measurements in ambient and vacuum conditions suggest that the observed RS is enabled by hydroxyl ions (OH^-)[2] that originate possibly from catalytic splitting of adsorbed water molecules in MoS_2[3]. Experimental observations in combination with analytical simulations further suggest that the electric field-driven movements of the mobile OH^- ions along the vertical MoS_2 layers influence the energy barrier at the Si/MoS_2 interface and induce the RS effect[4]. The observed ion-based plasticity may be exploited in ionic-electronic devices based on TMDs and other 2D materials for memristive applications. Furthermore, the device fabrication process used is fully scalable and semiconductor production compatible enabling integration of such novel 2D materials-based memristors into existing Si technology for future neuromorphic applications.

DEVICE FABRICATION



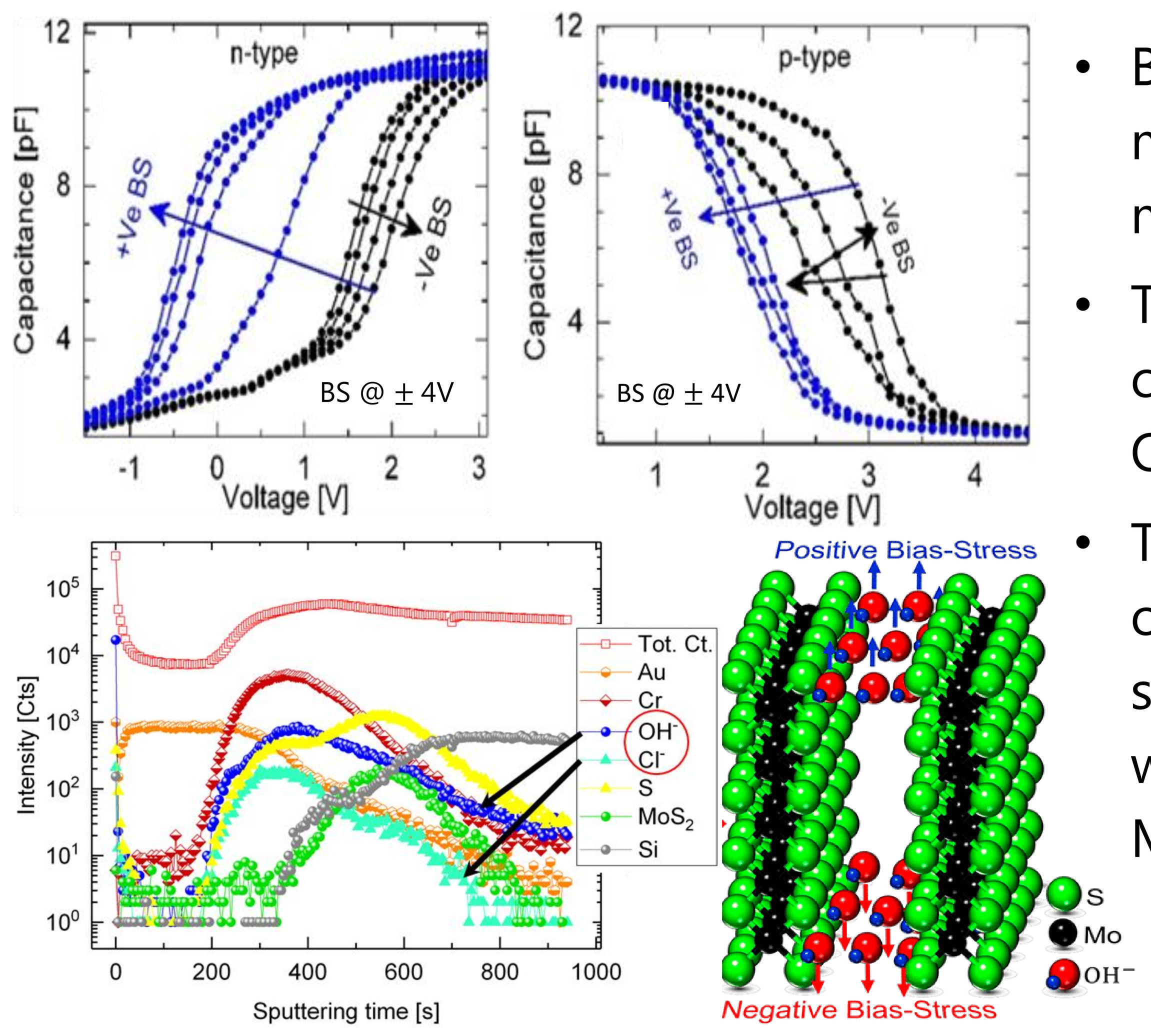
- Scalable and CMOS-compatible device fabrication process;
- Large-area MoS_2 growth using thermal annealing convertion (TAC) [4].

MoS_2 CHARACTERIZATION



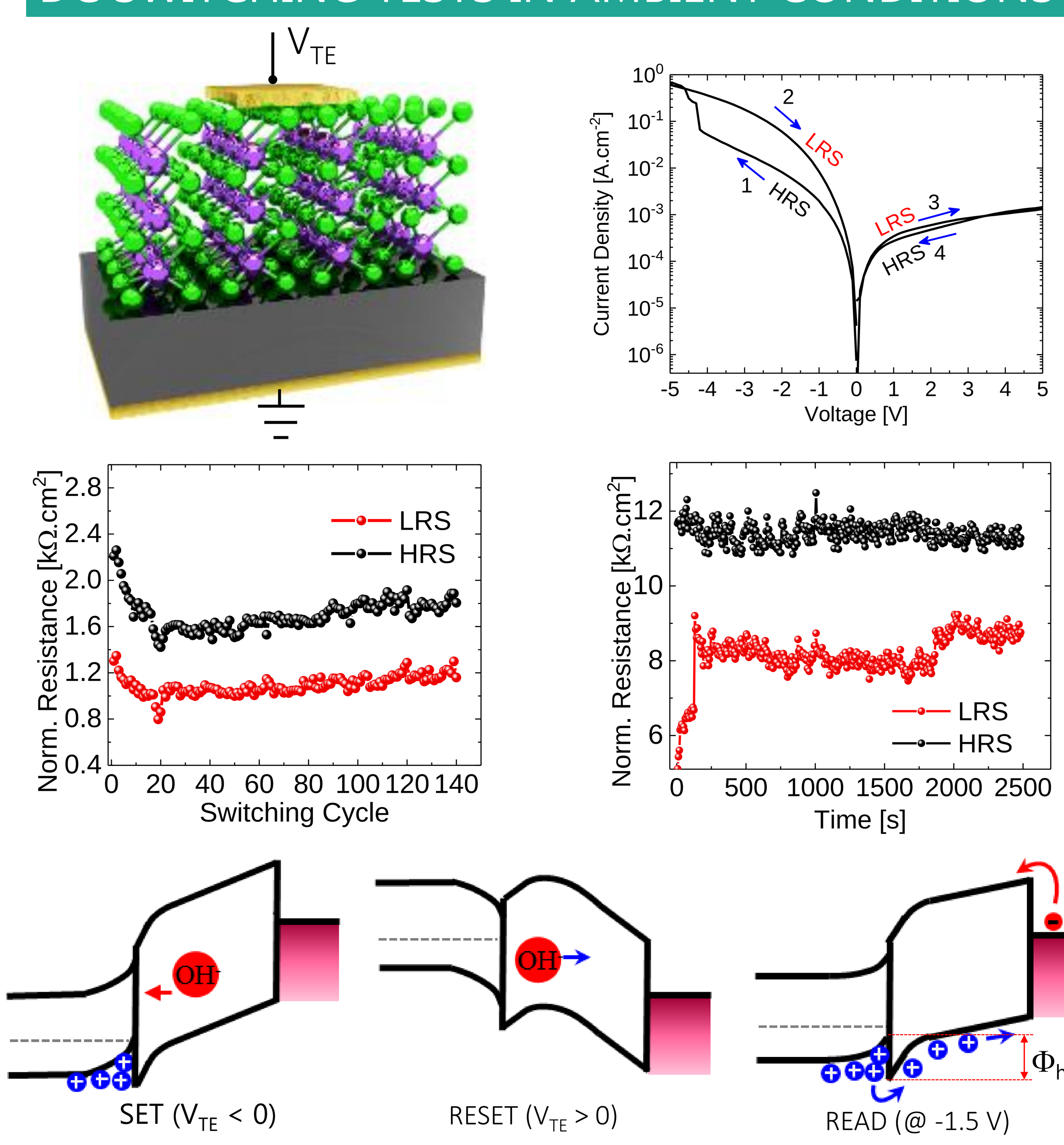
- AFM measurements indicate ~15 nm MoS_2 film;
- RAMAN and TEM investigations show MoS_2 with vertically aligned layers [4].

MOBILE OH^- IONS IN THE LAYERED NANOCRYSTALLINE MoS_2



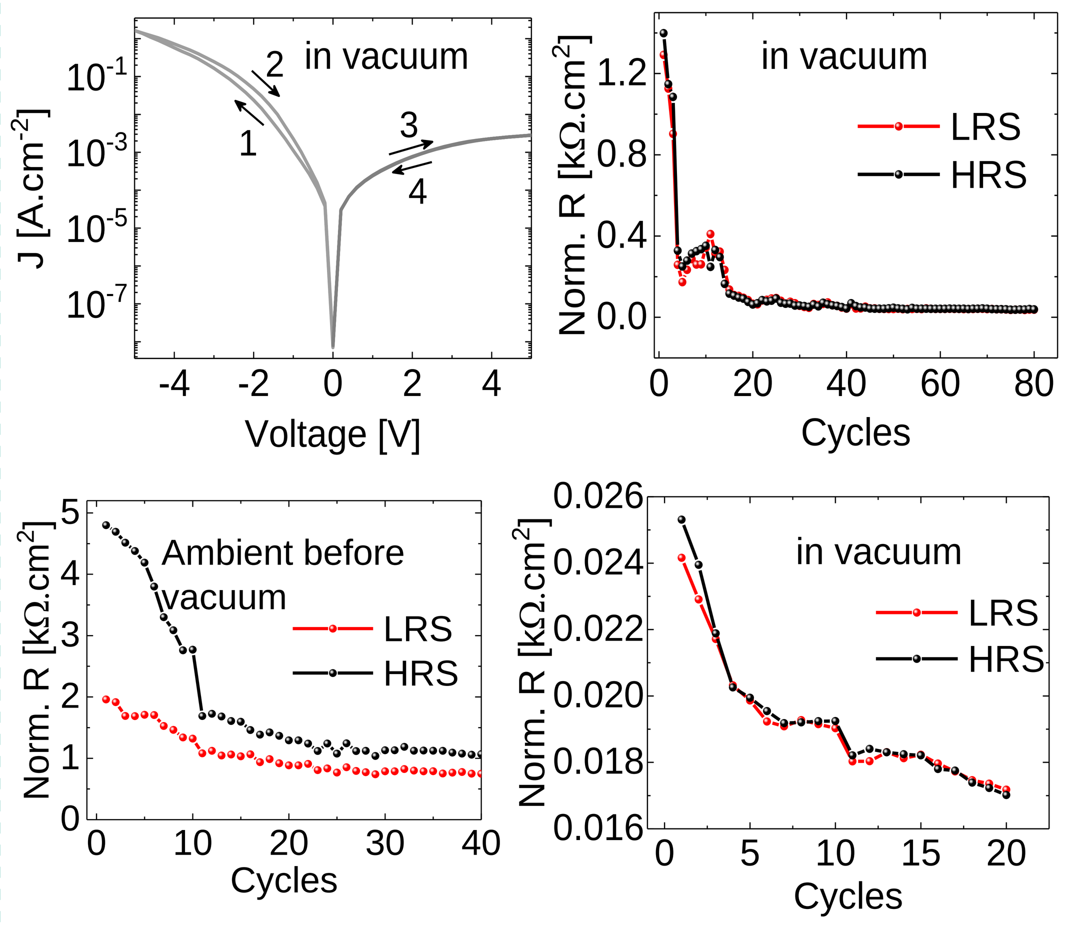
- Bias-stress C-V measurements indicate mobile charges;
- ToF-SIMS analysis confirms presence of OH^- ions;
- The OH^- ions possibly originate from catalytic splitting of adsorbed water molecules in MoS_2 [2].

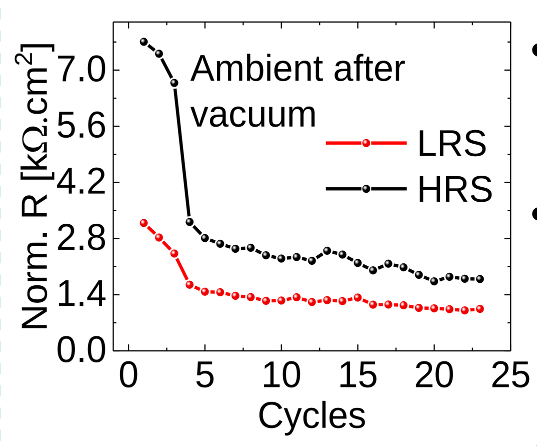
DC SWITCHING TESTS IN AMBIENT CONDITIONS



- I-V hysteresis shows bipolar and forming-free RS;
- DC switching with stable endurance and retention [4].

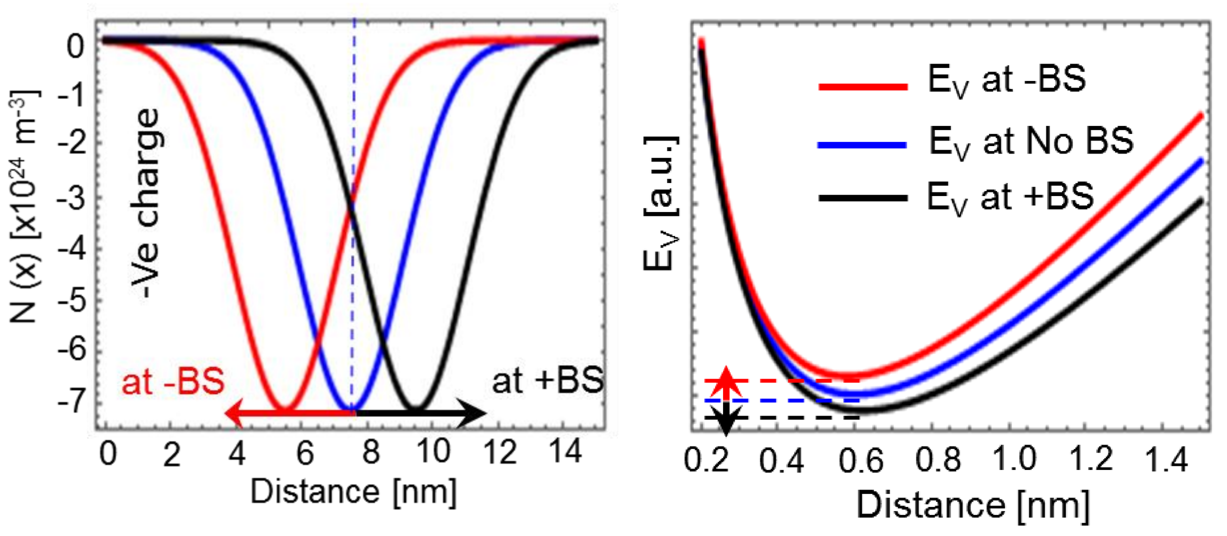
ORIGIN OF THE OBSERVED RS EFFECT





- Considerable RS in ambient;
- Negligible amount of RS ratio in vacuum;
- RS back in play again in ambient [4].

ANALYTICAL SIMULATION



- Bias-stress moves the OH^- ions in MoS_2;
- Position of the OH^- ion distribution influences the barrier height at the Si/MoS_2 interface [4].

CONCLUSIONS

- ❑ Hybrid Memristors with nanocrystalline MoS_2 fabricated on silicon;
- ❑ Non-volatile, bipolar and forming-free RS observed;
- ❑ Simulation results suggest that position of OH^- ion distribution tunes barrier at the Si/MoS_2 interface;
- ❑ Controlled switching tests confirm that the RS is driven by OH^- ions.

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