Ferroelectric Field Effect induced Metal-Insulator transition in ReS_2 via Epitaxial P(VDF-TrFE) Nanowires

Aram Pirali[1,2], Tianlin Li[1], Stephen Ducharme[1], and Xia Hong[1]

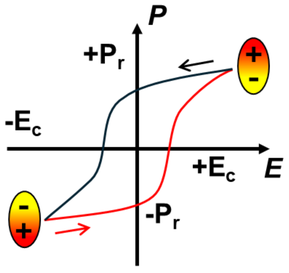
1. Department of Physics and Astronomy, University of Nebraska-Lincoln
2. Department of Chemical and Biomolecular Engineering, University of Nebraska-Lincoln

Abstract

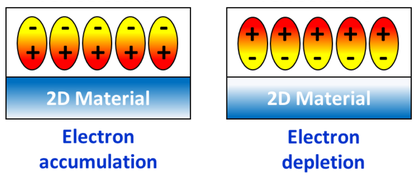
Ferroelectric-gated 2D van der Waals transistors are a promising venue for developing energy-efficient memory and logic devices. We investigate the ferroelectric field effect in few-layer ReS_2 gated by the ferroelectric polymer P(VDF-TrFE). Driven by epitaxial lattice coupling at the polymer-crystal interface, Langmuir-Blodgett deposited P(VDF-TrFE) self-assembles into closely packed nanowire arrays aligned perpendicular to the *b*-axis of ReS_2. Atomic force and piezoresponse force microscopy studies confirm that the nanowire structure and written polarization domains remain stable upon temperature cycling down to 2 K. With polarization reversal, the ferroelectric field effect produces nonvolatile current switching ratios exceeding 10^5 in 4-layer ReS_2 at room temperature and switches the channel between *n*-type and *p*-type conduction. Temperature-dependent transport measurements reveal a gate-tunable metal-insulator transition in the polarization-down state around 200 K. Notably, a non-monotonic feature in the resistance-temperature curve at 10 V suggests the transition may be first-order, motivating future thermal hysteresis measurements.

Background

Ferroelectrics

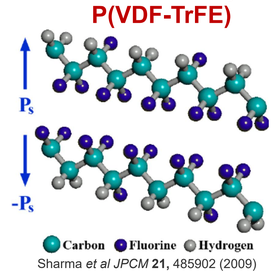


- Nonvolatile polarization
- Switchable via external electric field larger than the coercive field



- **Nanoscale programmable**

Ferroelectric polymer P(VDF-TrFE)



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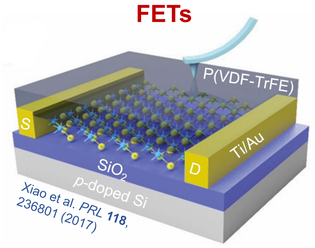
- Polarization: 5−10 μC/cm²
- Solution-based low-cost fabrication
- Flexible and transparent

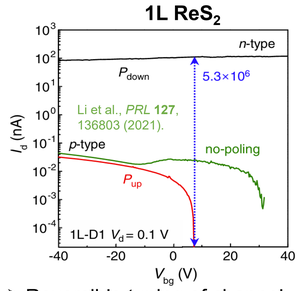
Schematic for PVDF-gated FETs



- P(VDF-TrFE) serves as a nonvolatile ferroelectric top gate
- Polarization direction controls carrier density in the channel

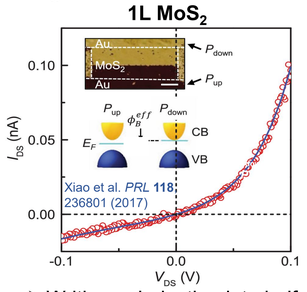
Combining polarization doping with nanoscale domain control

Nonvolatile field effect in 1L ReS_2



- Reversible tuning of channel current by orders of magnitude
- Switching between n-type and p-type conduction

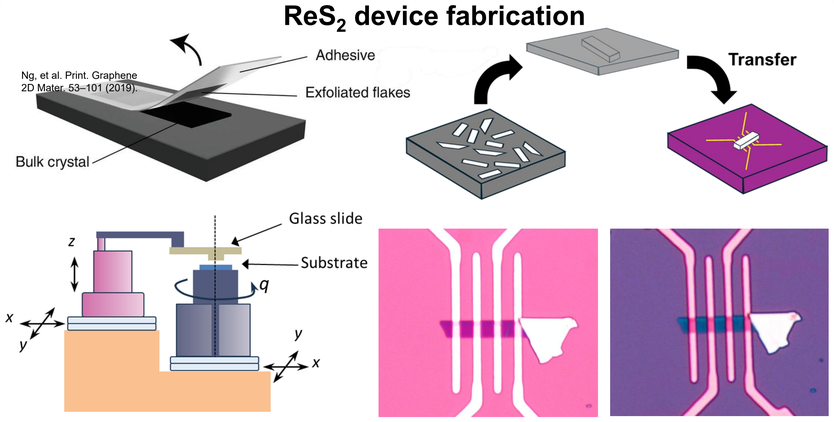
Programmable junction state in 1L MoS_2



- Writing polarization into half-P_{up}/half-P_{down} domain structure creates a programmable Schottky barrier junction

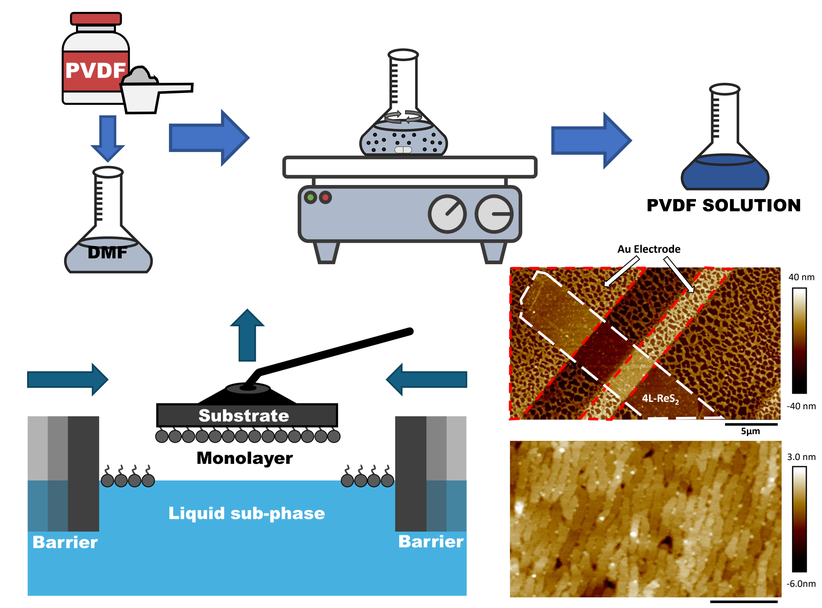
Methods

ReS_2 device fabrication

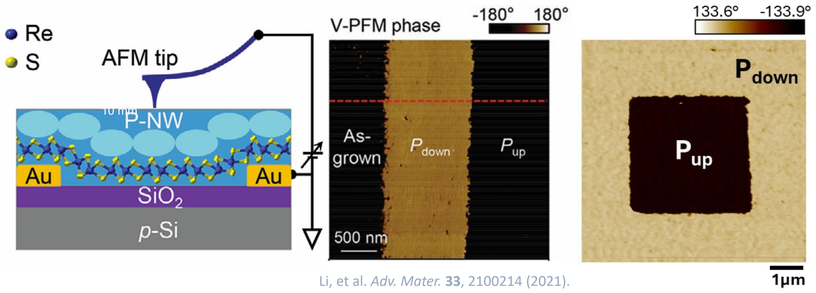


- **Dry Transfer Method:** ReS_2 flakes are mechanically exfoliated onto a gel-film stamp, then aligned and contacted with a SiO_2 substrate with pre-patterned gold electrodes

Deposition of P(VDF-TrFE) using Langmuir Blodgett Technique



- Polymer solutions are first made by dissolving bulk P(VDF-TrFE) in DMF
- Solution deposited dropwise onto water surface, spreading into a film at the air-water interface in KSV Nima Langmuir Trough
- Substrate is horizontally dipped into the trough to deposit approximately one monolayer



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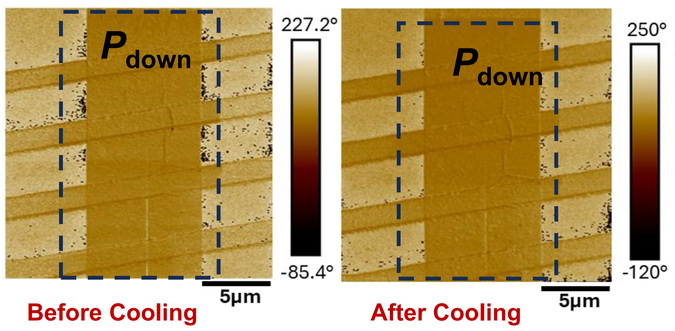
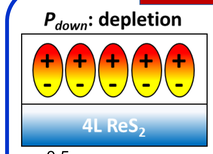
- Polarization domains locally written via conductive AFM
- Low-temperature transport characterized down to 2 K



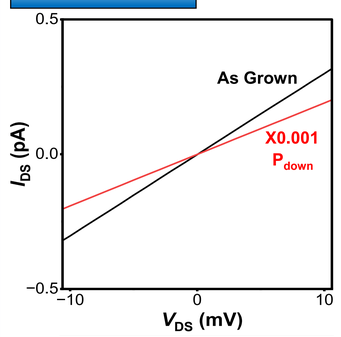
- Polarization remains completely intact after temperature cycling down to 2 K for weeks at a time

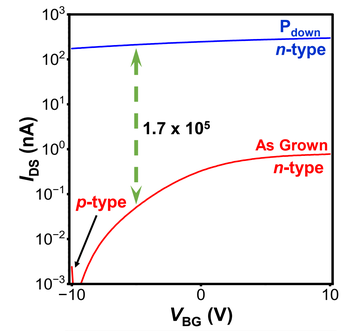
Polarization is stable!

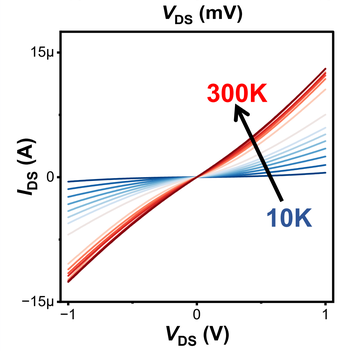
Results



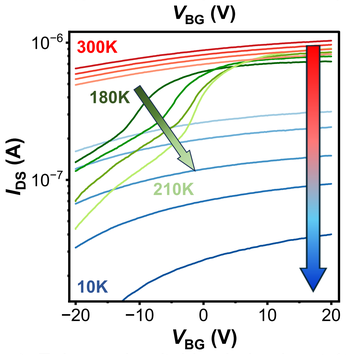
- P_{down} polarization corresponds to more conductive state
- Nonvolatile modulation at 300 K with current modulation by a factor of 1000
- Current switching ratio reaches 10^5 in 4L ReS_2



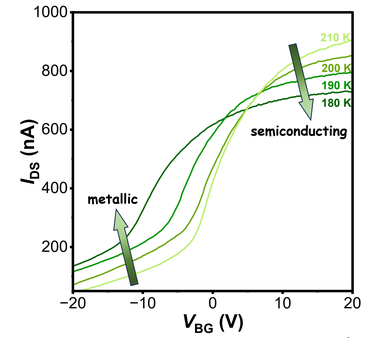


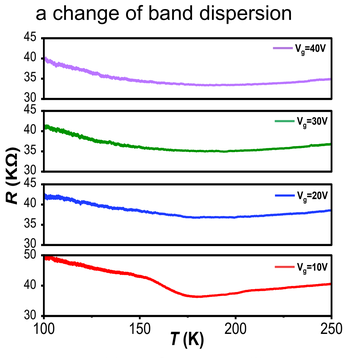


- Resistance increases with decreasing temperature
- Still behaves as a semiconductor



- Enhanced switching behavior at 180 K - 210 K
- Crossing of transfer curves indicating a change of band dispersion





- Metallic at negative gate voltage
- Semiconducting at positive gate voltage
- Device transitions from metallic to insulating near 180 K
- 10 V curve suggests a first-order transition

Conclusion

- Ferroelectric LB deposited P(VDF-TrFE)/few-layer ReS_2 FETs successfully fabricated
- P(VDF-TrFE)/4L ReS_2 devices exhibit nonvolatile ferroelectric field effect
- Stability of written domains has been established through temperature cycling
- Metal-insulator transition has been observed in 4L ReS_2 in the P_{down} state

Acknowledgement

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