Integrating 2D Ferroelectric $CuInP_2S_6$ with MoS_2 Field Effect Transistor

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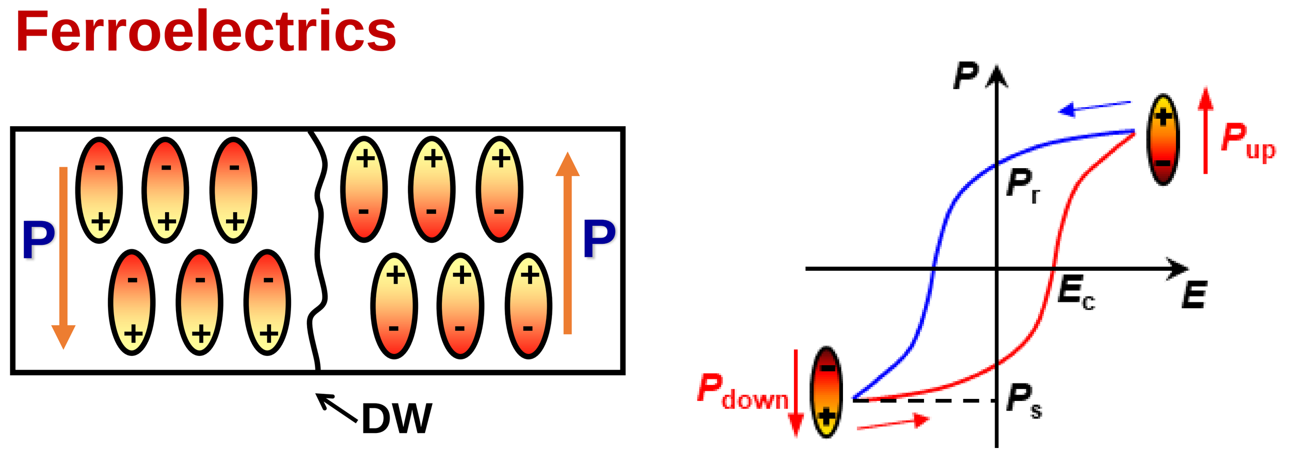
Abstract

This study examined the gating effect of two dimensional (2D) van der Waals (vdW) ferroelectrics $CuInP_2S_6$ (CIPS) in modulation of channel current of 2D semiconductor MoS_2 field effect transistor (FET). Recently, ferroelectricity has been discovered in 2D vdW materials, such as SnTe, In_2Se_3, and CIPS. These materials can potentially preserve ferroelectricity in the monoatomic layer limit, making them promising for developing ferroelectric-based 2D nanoelectronics.

In this study, we explored the gating effect on 2D MoS_2 FET top gated by 2D vdW ferroelectrics CIPS. The polarizations of CIPS on different base layers are robust after domain writing using conductive atomic force microscopy (AFM). The channel conductance has been sufficiently suppressed after transferring the CIPS top gate on MoS_2, which is due to the charge carrier depletion induced by the polarization of as-grown CIPS. In the future study, we could use piezoresponse force microscopy (PFM) to switch the polarization of the CIPS top gate into the P_{up} and P_{down} states, which might induce non-volatile modulation of channel current and achieve the different current on/off ratios. Our research can provide important material parameters for designing CIPS-based nanoelectronic devices, paving the path for their implementation in programmable, flexible nonvolatile memory, neuromorphic computing, and optoelectronic applications.

Introduction

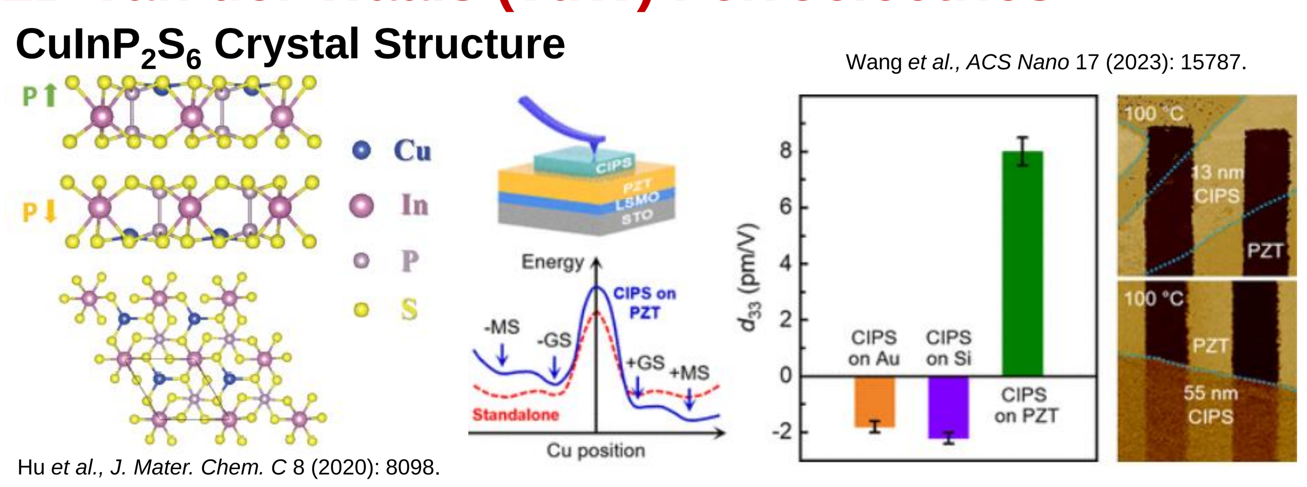
Ferroelectrics



- Ferroelectric shows the piezoelectric response under external electric fields
- Non-volatile polarization and switchable hysteresis

2D van der Waals (vdW) Ferroelectrics

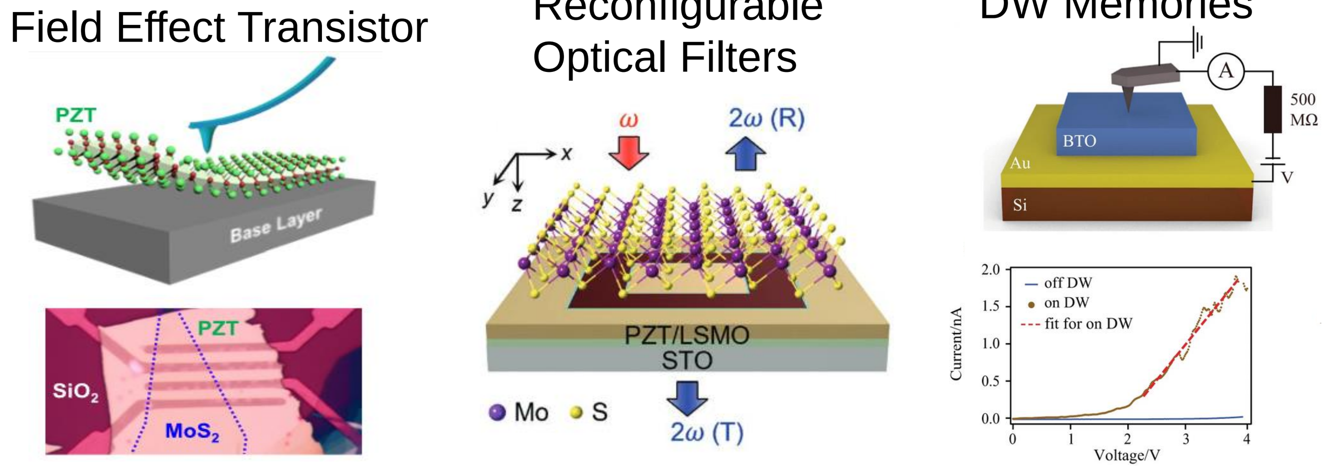
$CuInP_2S_6$ Crystal Structure



- 2D vdW ferroelectrics can preserve ferroelectricity in the atomic layer limit, which is compromised for conventional ferroelectrics

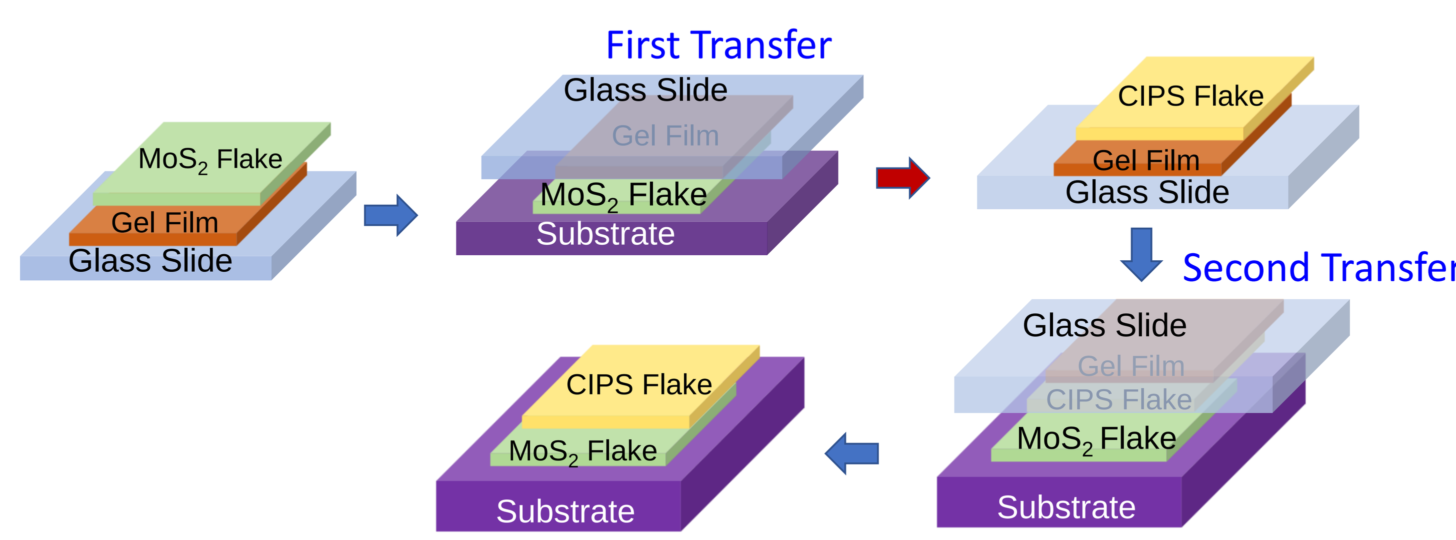
Application

Field Effect Transistor | Reconfigurable Optical Filters | DW Memories

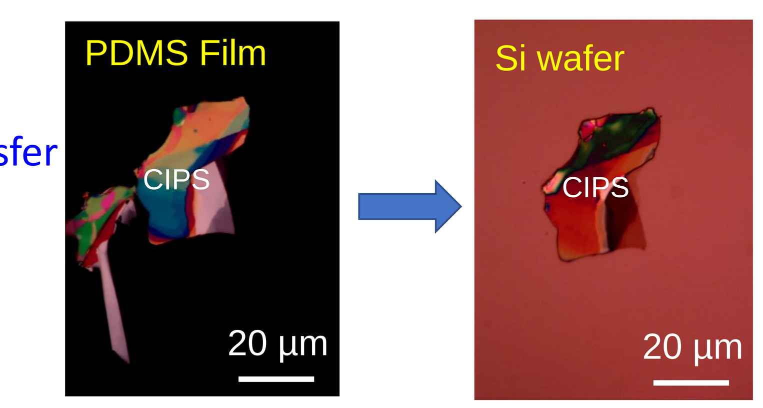


Methods

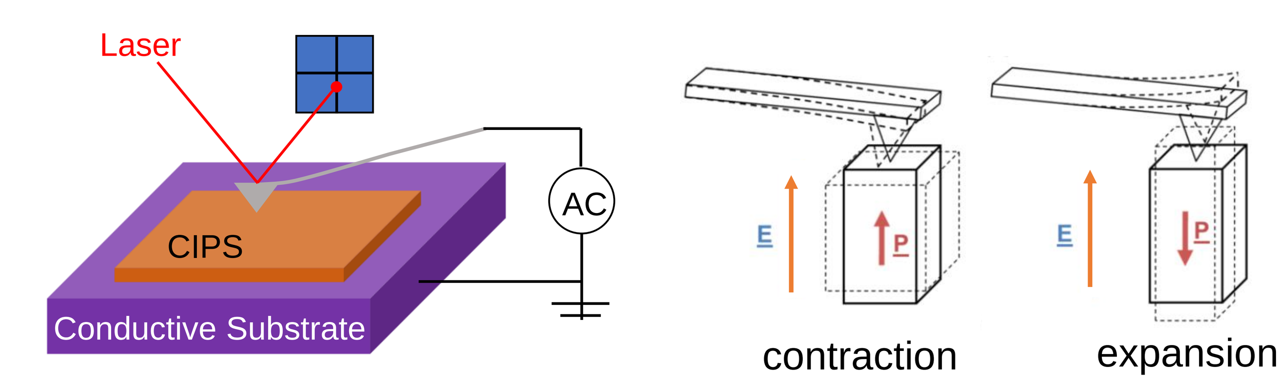
Transfer: CIPS Flake onto MoS_2 Flake



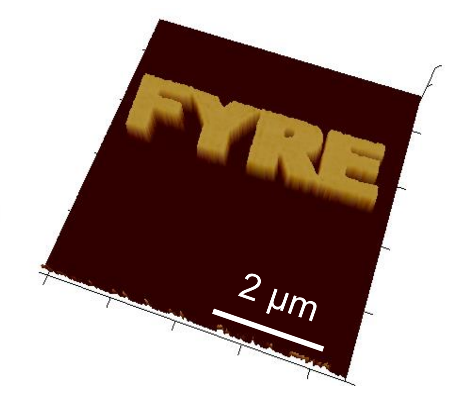
Optical images of CIPS



Characterization via Piezoresponse Force Microscopy

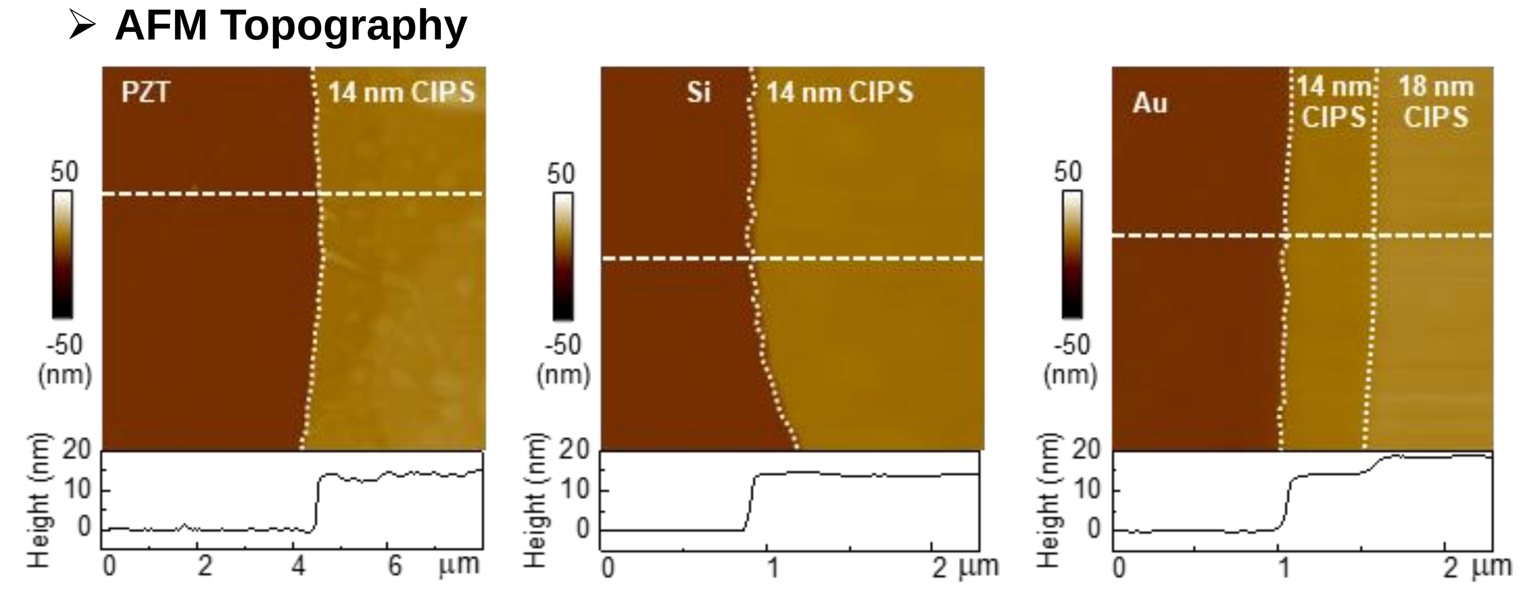


- Program polar patterns in ferroelectric thin films



PFM Imaging of CIPS flakes

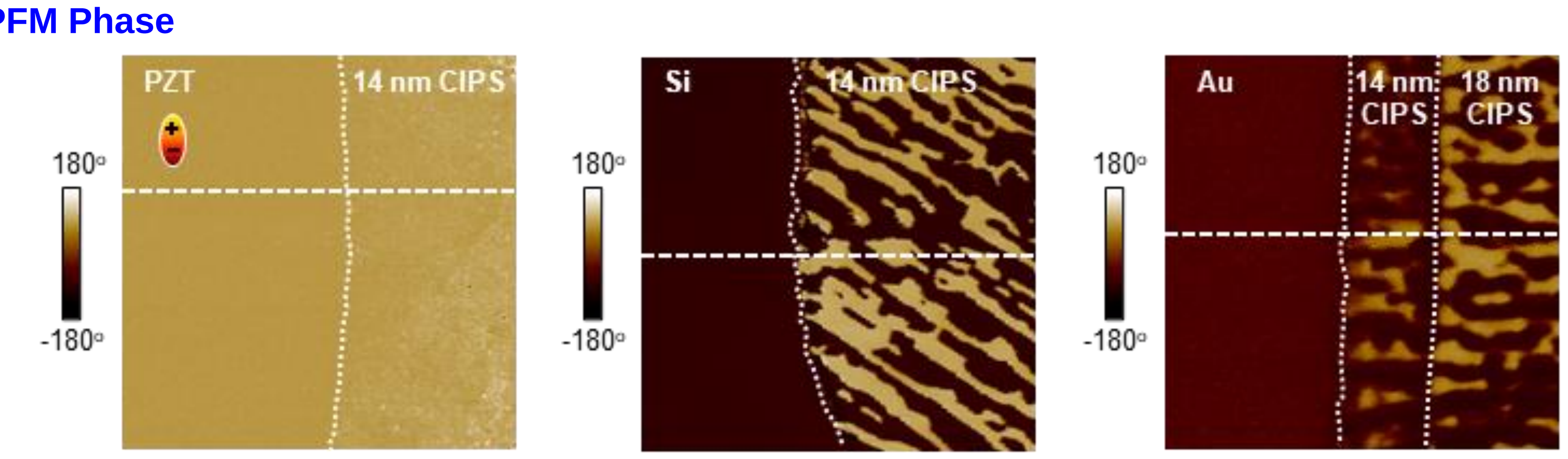
➢ AFM Topography



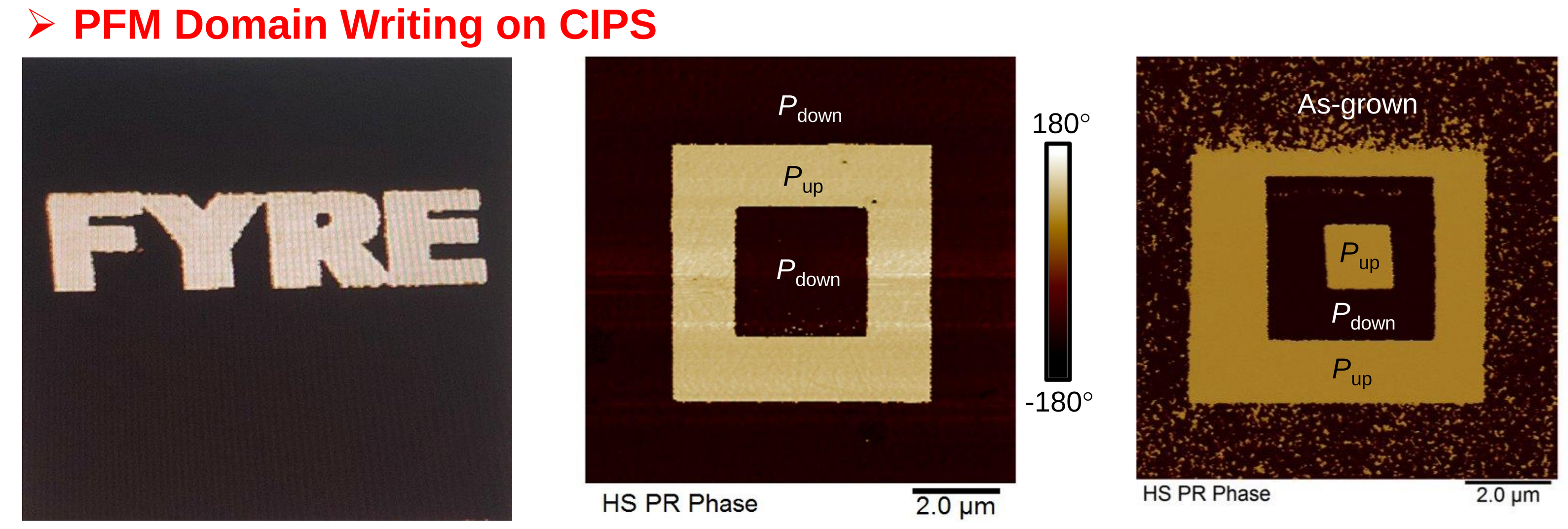
➢ CIPS on conductive Si and Au: Spontaneous polarization formation of stripe domains

➢ Thin CIPS on PZT: Enhanced polar alignment

➢ PFM Phase



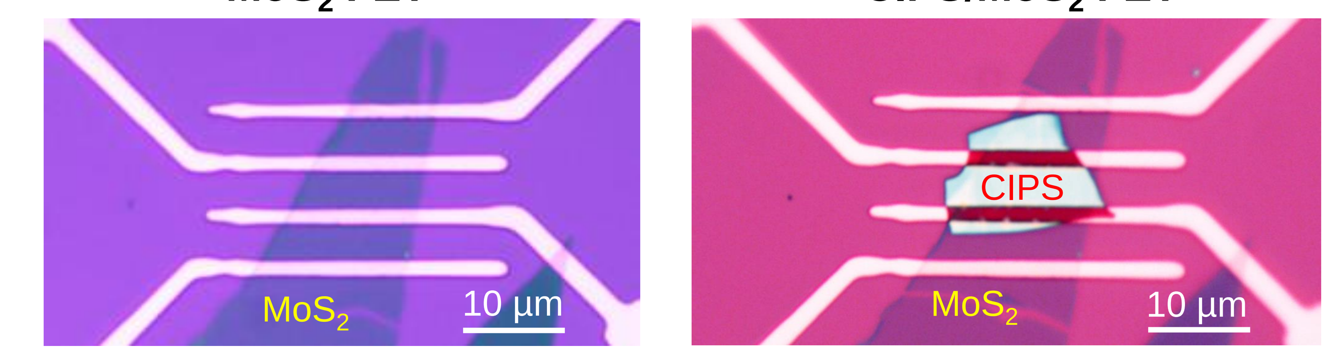
➢ PFM Domain Writing on CIPS



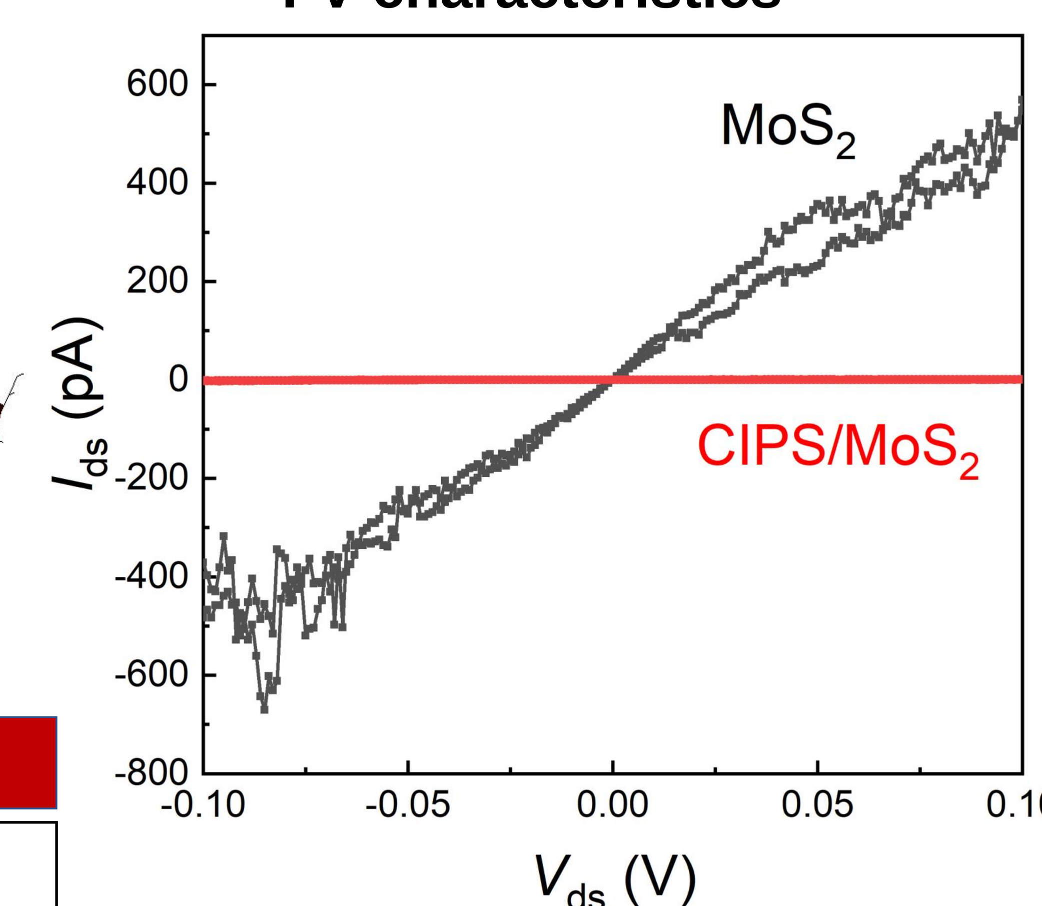
➢ As-grown state is inhomogeneous

➢ Robust polarization switching after domain writing

CIPS Top-gated MoS_2 FET



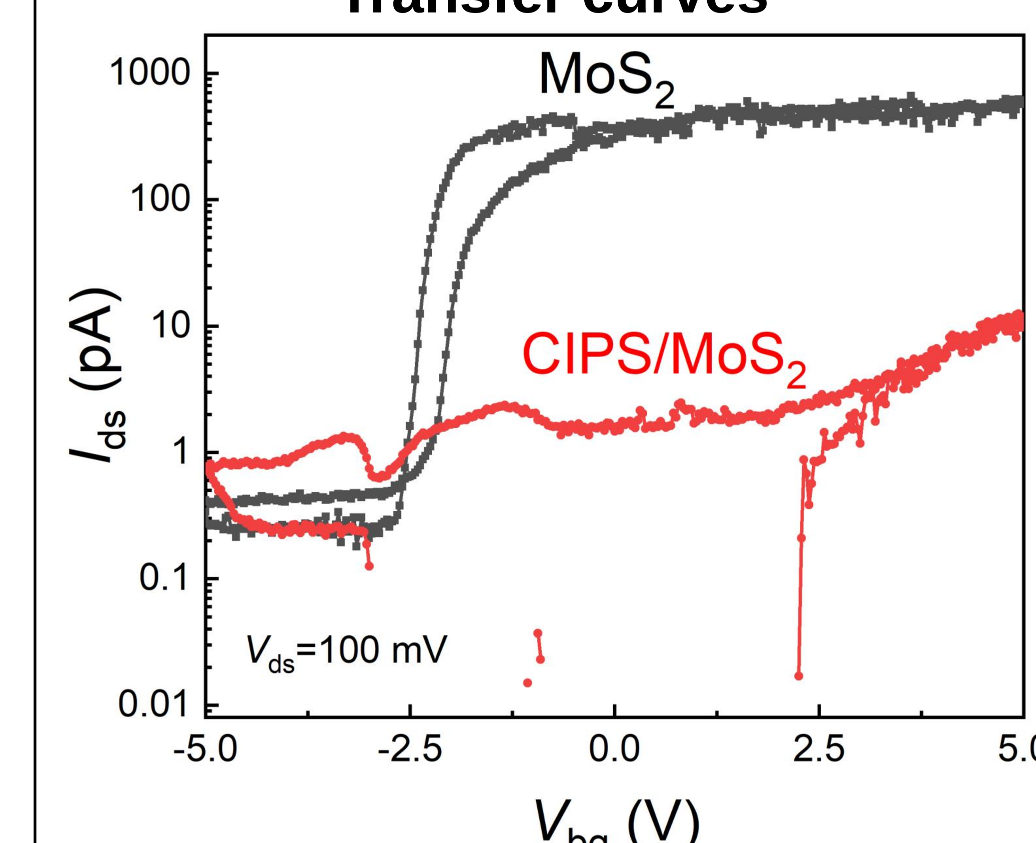
I-V characteristics



➢ I_{ds} is suppressed by over 3 orders of magnitude after transferring the CIPS top gate

➢ The decreased channel current is due to the depressed charge carrier density induced by polarization of CIPS

Transfer curves



➢ The transfer curve has been shifted to the lower right-hand side after transferring CIPS

Conclusion

➢ The domain of 2D ferroelectrics CIPS on Au and Si is stripe shape and the polar alignment is greatly enhanced when transferred on PZT base layer.

➢ The polarization of CIPS after domain writing is robust.

➢ The channel current of MoS_2 FET is greatly suppressed after transferring CIPS top gate.

➢ In the future study, we could polarize the CIPS top gate into P_{up} and P_{down} states to induce the non-volatile modulation of channel current.

Acknowledgements

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