Probing 2D Ferroelectricity in van der Waals $CuInP_2S_6$ Using Piezoresponse Force Microscopy

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NCMN Nebraska Center for Materials and Nanoscience University of Nebraska

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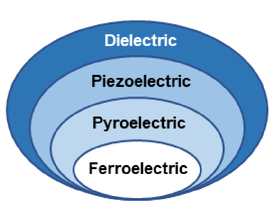
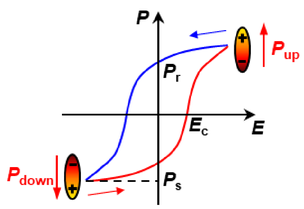
Abstract

We studied the ferroelectric properties of atomically thin $CuInP_2S_6$ (CIPS) prepared on a variety of substrates. Using piezoresponse force microscopy, we imaged the ferroelectric domains in CIPS flakes with different thicknesses, from which we can extract the polar axis direction and the characteristics of domain formation in CIPS. We expect to reveal the substrates screening and interfacial polar coupling on the thickness scaling limit of this emerging 2D ferroelectrics. Our research can provide valuable information for the technological application of CIPS.

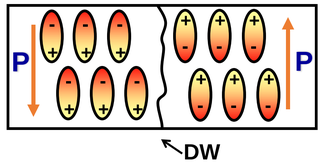
Introduction

Ferroelectrics





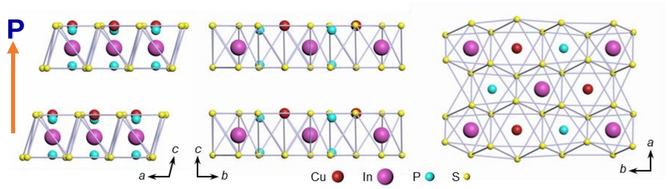
- Ferroelectric shows the piezoelectric response under external electric fields
- Non-volatile polarization and switchable hysteresis



- Domain: one area with the same polarization direction
- Domain Wall (DW): boundary between two oppositely polarized domains

2D van der Waals (vdW) Ferroelectrics

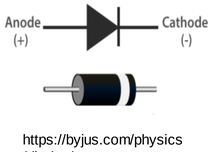
$CuInP_2S_6$ Structure (2 atomic layer)



- 2D Materials: layered down to nanoscale thickness
- Ultrathin CIPS exhibits room-temperature ferroelectricity and large polarization
- 2D vdW ferroelectrics can preserve ferroelectricity in the atomic layer limit, which is compromised for conventional ferroelectrics (oxides, polymer)

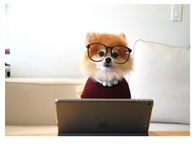
Application

Diode Rectifier



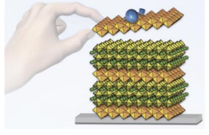
https://byjus.com/physics/diodes/

Memory Device



https://unsplash.com/photos/gySMaocSdqs

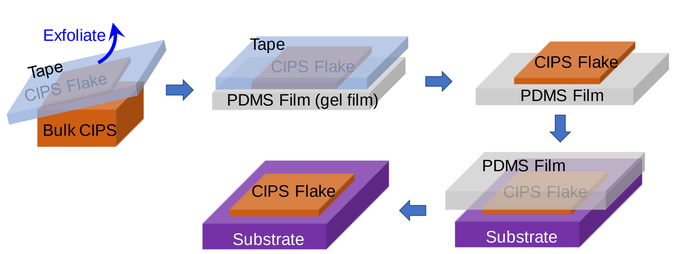
Artificial multiferroic



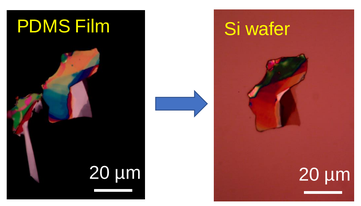
Novoselov et al., Science 353, 9439 (2016)

Methods

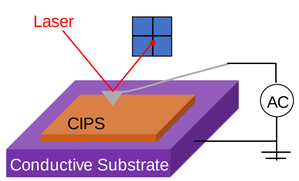
Sample preparation: Nanoscale-thickness CIPS flake

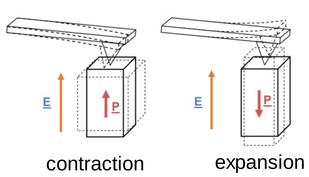


Optical images

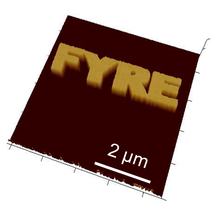


Characterization via Piezoresponse Force Microscopy (PFM)



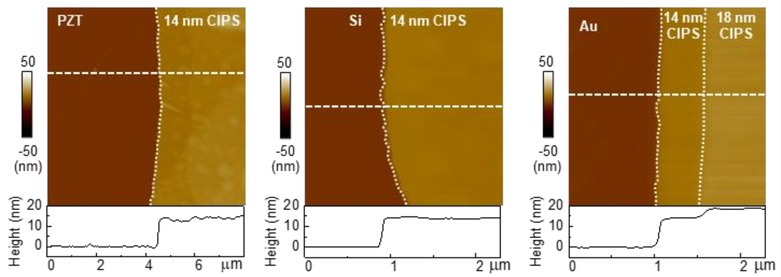


- Program polar patterns in ferroelectric thin films

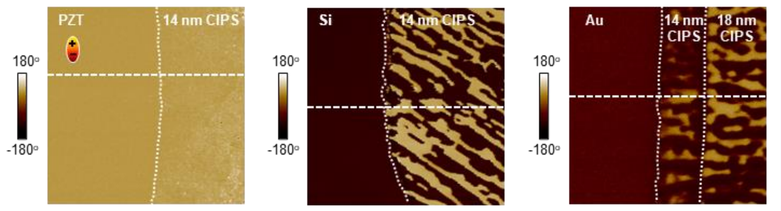


PFM Imaging

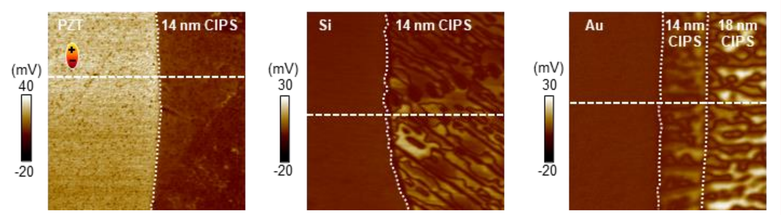
➢ **AFM Topography**



➢ **CIPS Phase**



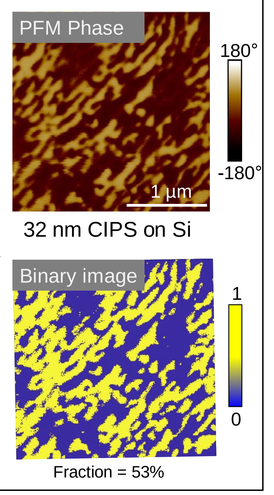
➢ **CIPS Amplitude**



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

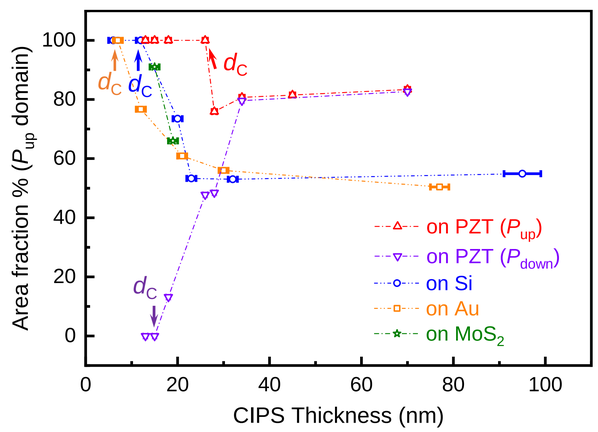
➢ Thin CIPS on PZT: Enhanced polar alignment

Image processing



Result

Thickness-dependent polarization distribution of CIPS on different base layers



➢ **For CIPS on Si and Au:**

- Below critical thickness (d_C), polarization is fully aligned upward

➢ **For CIPS on PZT:**

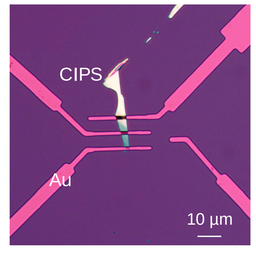
- Thin CIPS (< 18 nm) polarization fully conform to that of underlying PZT
- Thick CIPS on PZT shows predominant polarization up (P_{up})

Conclusion

1. CIPS prefers P_{up} over P_{down} pristine domains in ultrathin thickness (<20 nm)
2. CIPS polar alignment is significantly enhanced by underlying PZT
3. CIPS has the largest d_C on P_{up} domain of PZT , which is possibly due to the interfacial structure distortion between CIPS and PZT

Future Research

CIPS device on Si



- Fabricate nanoscale devices by transferring CIPS on PZT and Si base layer
- Explore any emergent electronic transportation at the CIPS/PZT interface

Acknowledgements

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