Two-Dimensional van der Waals Materials Based Nonvolatile Memory Field-Effect Transistors

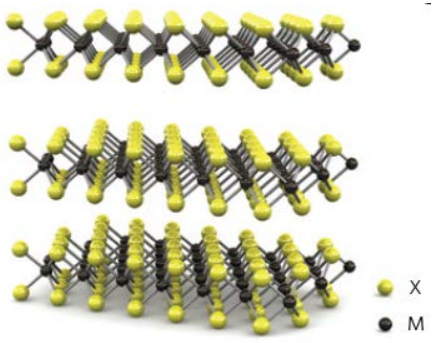
Do Kyung Hwang

Center for Opto-Electronic Materials and Devices, Korea Institute of Science and Technology (KIST)

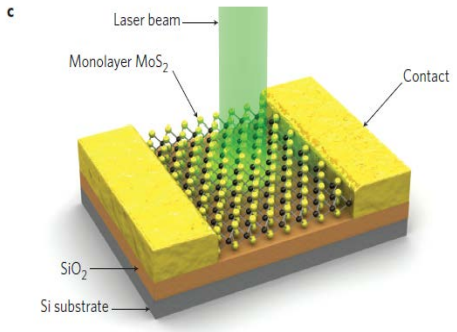
dkhwang@kist.re.kr

2-D van der Waals Materials beyond Graphene

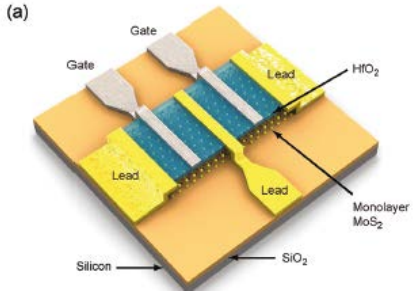
- Transition Metal Dichalcogenide (TMD)



M	X
Ti, Hf, Zr	S, Se, Te
V, Nb, Ta	
Mo, W	
Tc, Re	
Pd, Pt	

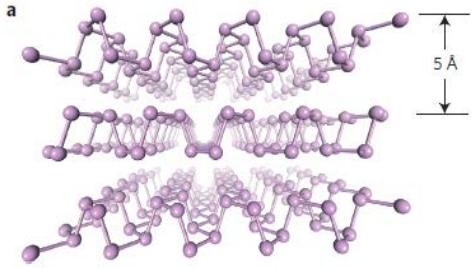


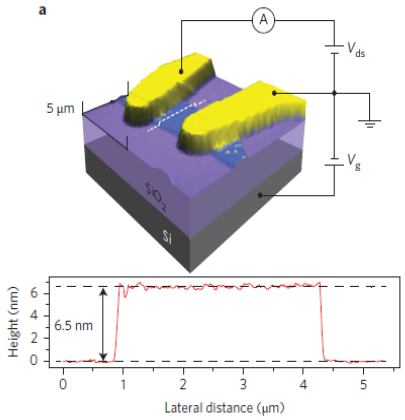
O. Lopez-Sanchez *et al*. *Nat. Nanotechnol.* **8**, 497 (2013)



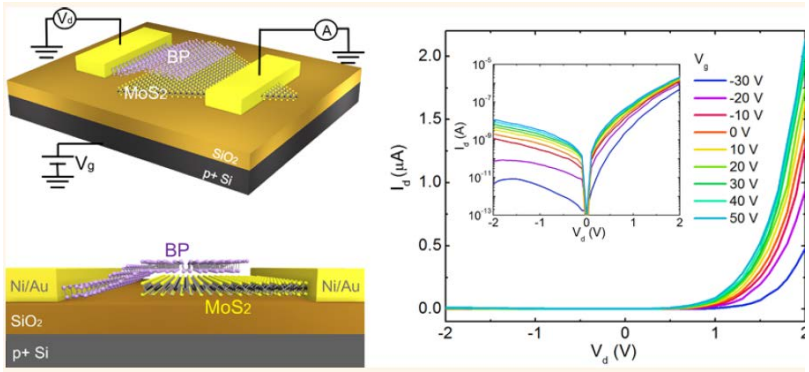
B. Radisavljevic *et al*. *ACS Nano* **5**, 9934 (2011)

- Black phosphorous (BP)





L. Li *et al*. *Nat. Nanotechnol.* **9**, 372 (2014)



Y. Deng *et al*. *ACS Nano* **8**, 8292 (2014)

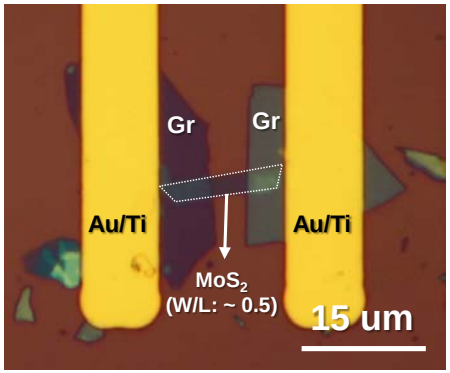
Why 2D vdWs Nanosheets ?

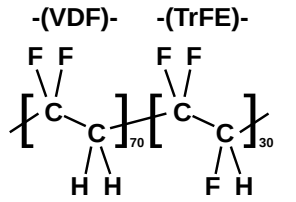
- They are hot materials for future semiconductor.
- They have very high carrier mobility.
- They show a quantum confinement effect .

MoS_2 and BP ferroelectric FETs

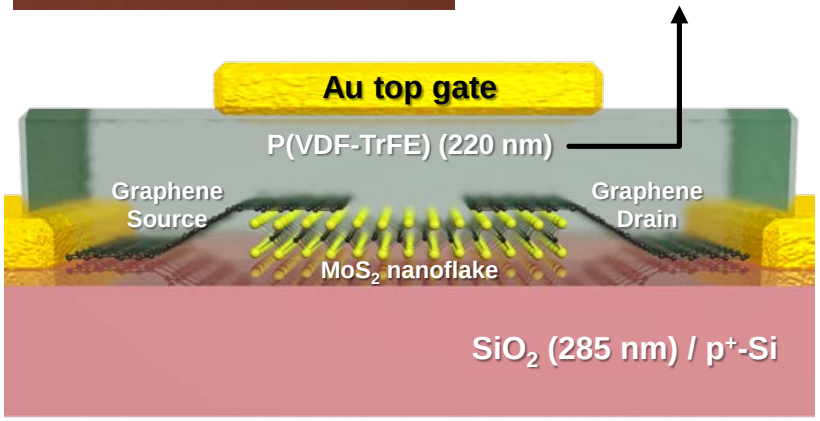
MoS_2 FeFETs

- MoS_2 FeFET with graphene S/D



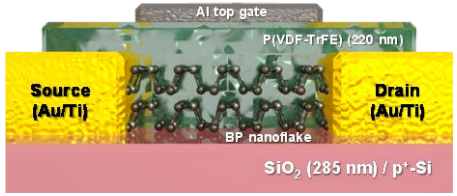


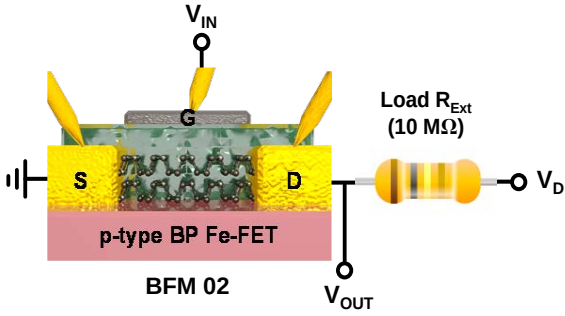
P(VDF-TrFE) copolymer



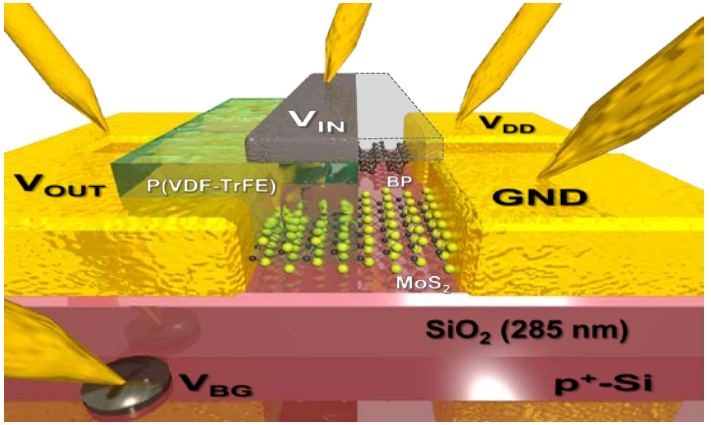
BP FeFETs

- BP FeFET unit device and Resistive-load inverter circuit



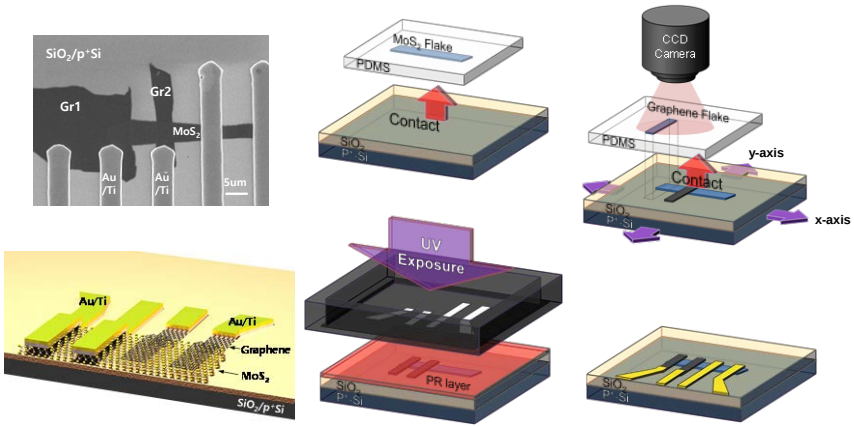


- *p*-BP and *n*-MoS_2 CMOS inverter circuit

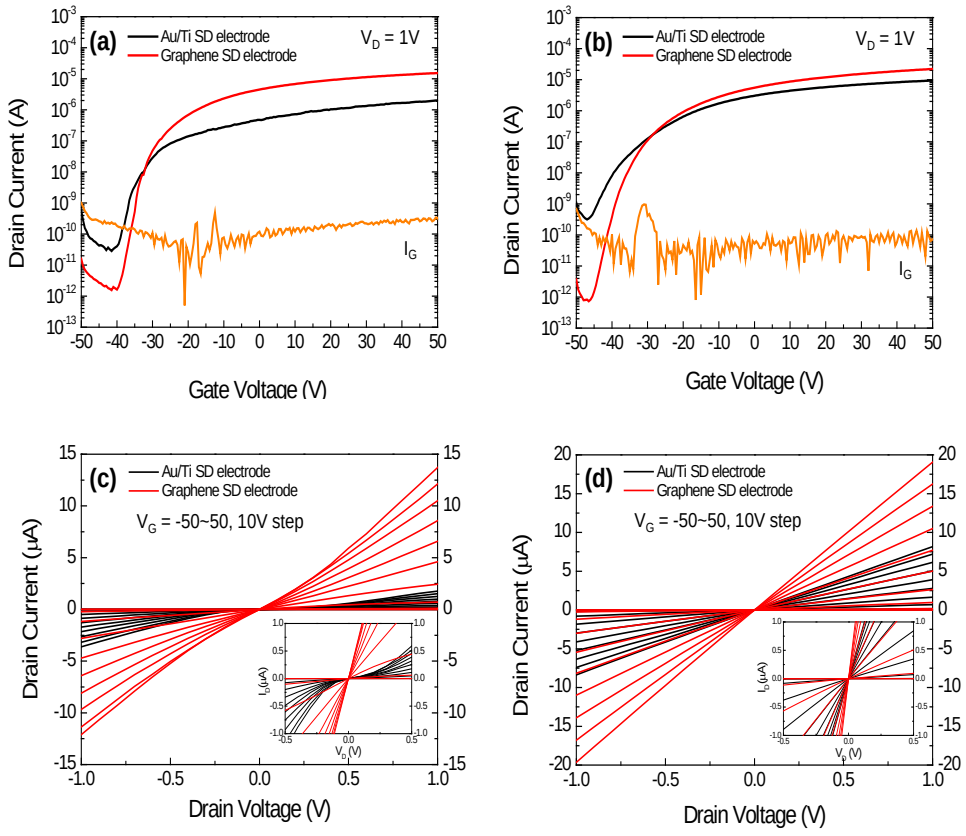


MoS_2 FETs with Graphene S/D

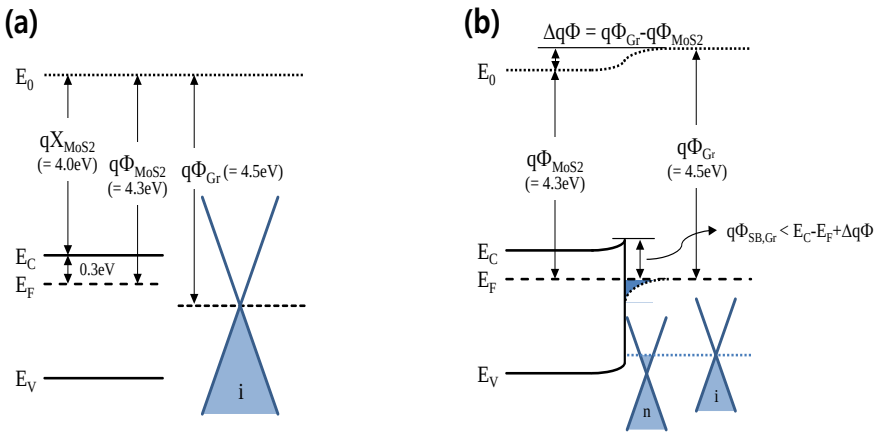
- **Direct imprinting method**



- **Transfer and output characteristics**



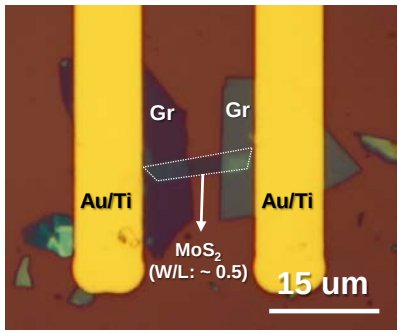
- **Graphene S/D electrode for MoS_2**

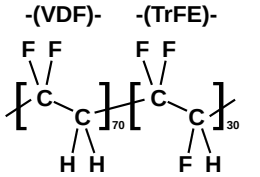


Graphene S/D electrode: superior ohmic or ON/OFF current behavior to those of Au/Ti due to modulated work function according to applied gate bias

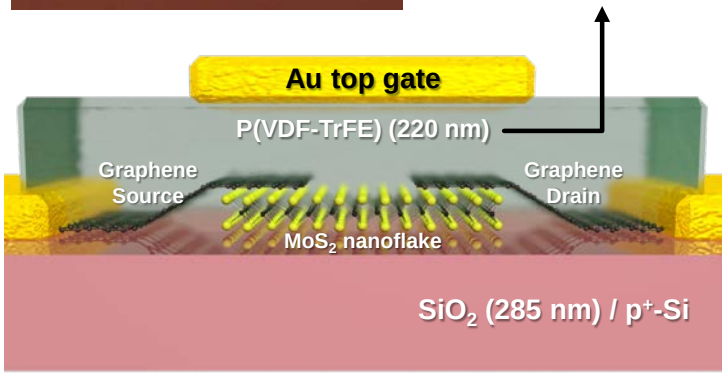
MoS_2 based ferroelectric field-effect transistors (FeFETs)

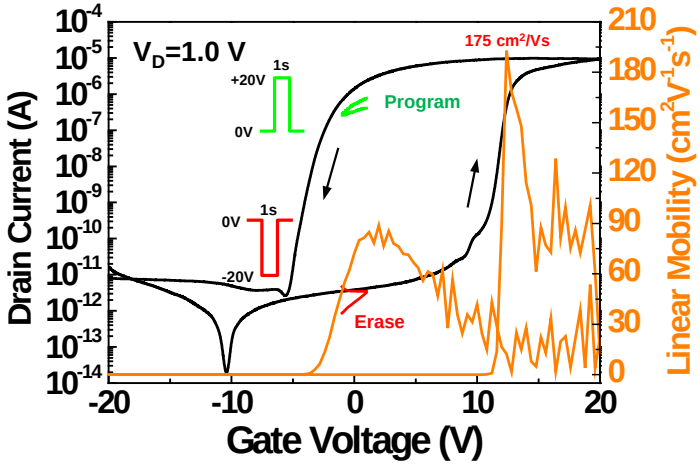
- MoS_2 FeFET with P(VDF-TrFE)



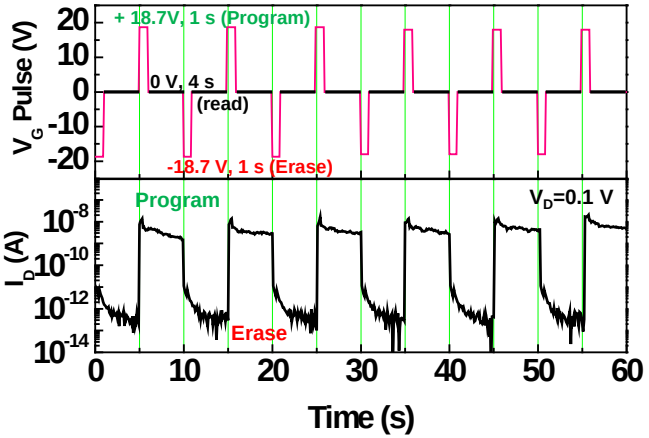


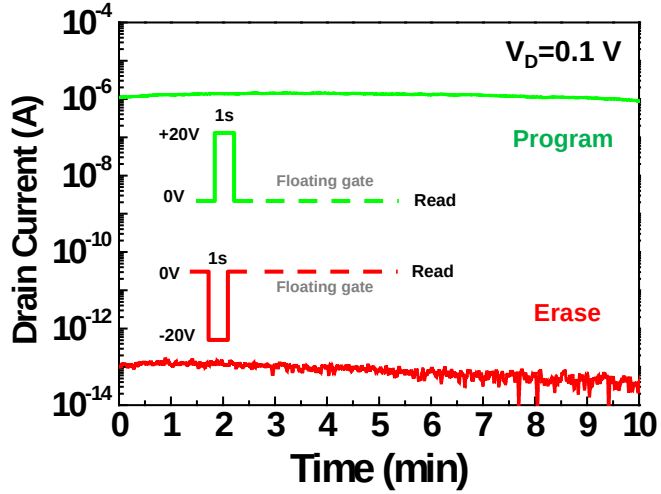
P(VDF-TrFE) copolymer





- Dynamic and Retention properties

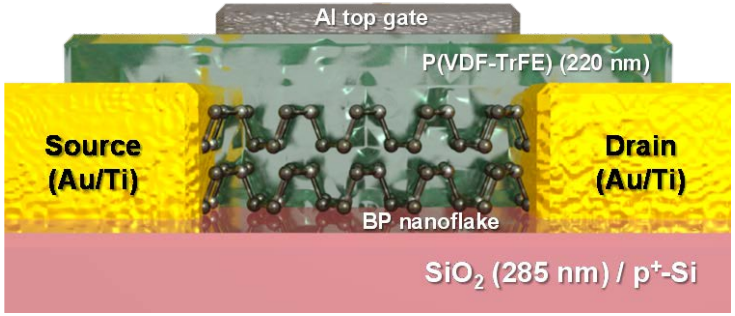




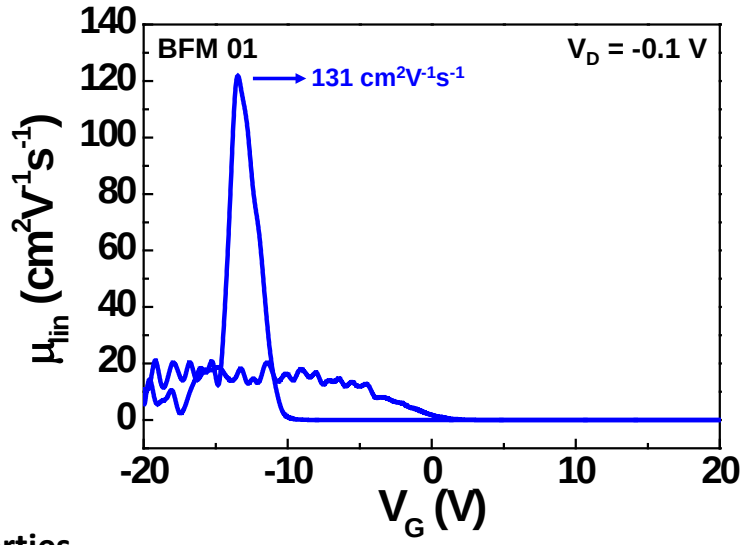
MoS_2 FeFET : Highest mobility of 175 cm^2/V s , memory window > 15 V, proper dynamic and retention properties

BP based FeFETs and Memory circuits (1)

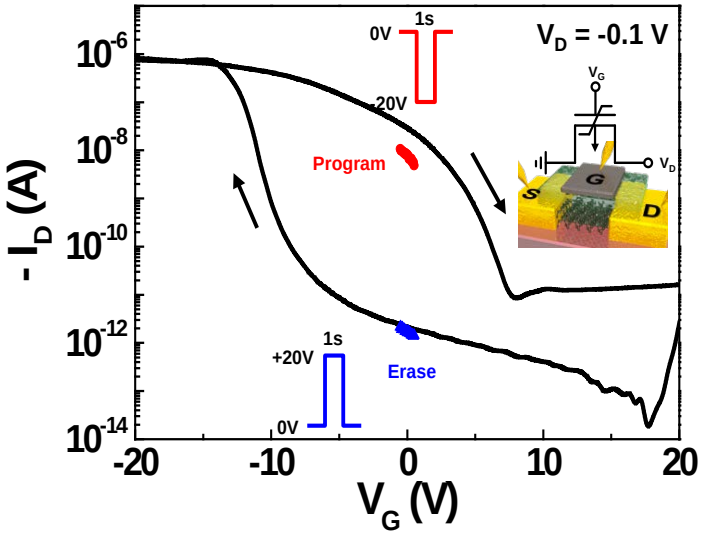
- BP FeFET with P(VDF-TrFE)

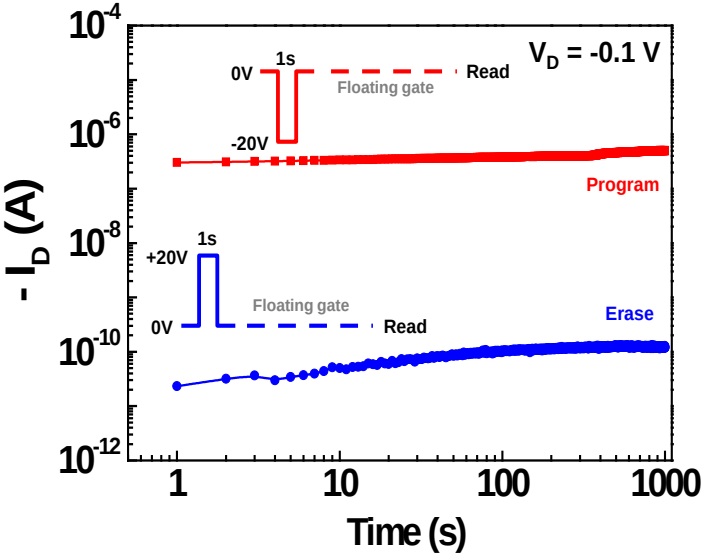


- Linear Mobility



- Memory static and retention properties





Memory window

: 15 V

Memory on-off

: 10^6

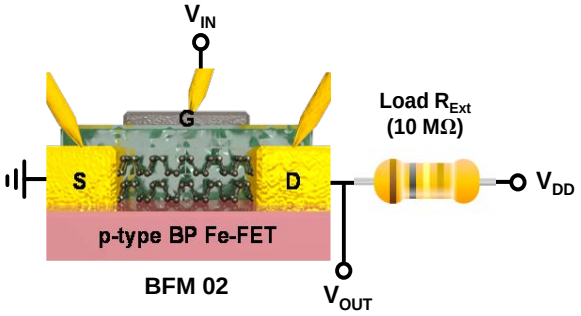
Mobility

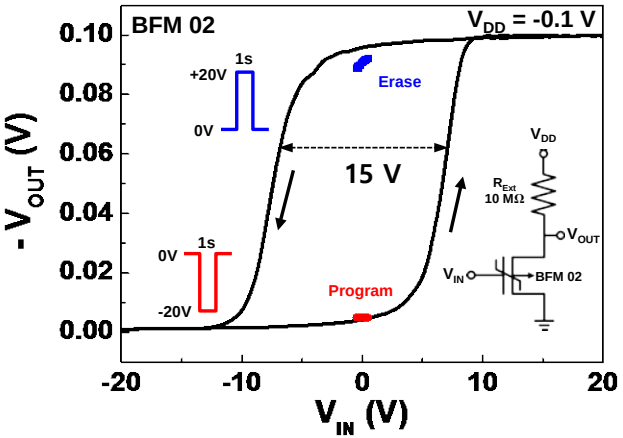
: 131 cm^2/Vs

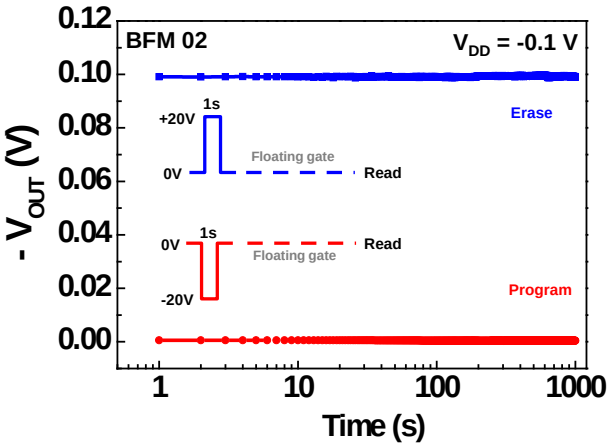
Y. T. Lee *et al*. ACS Nano DOI: 10.1021/acsnano.5b04592 (2015)

BP based FeFETs and Memory circuits (2)

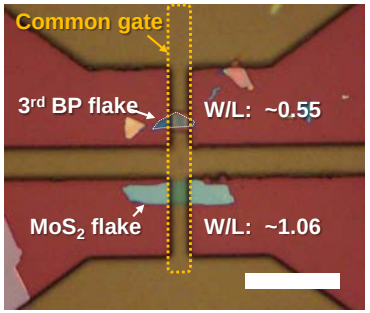
- Resistive-load inverter circuit

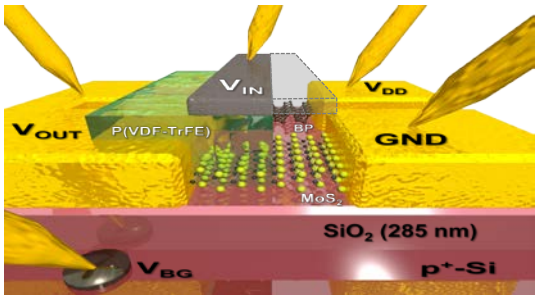


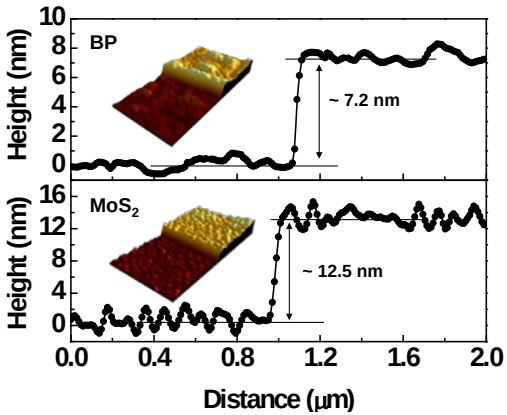


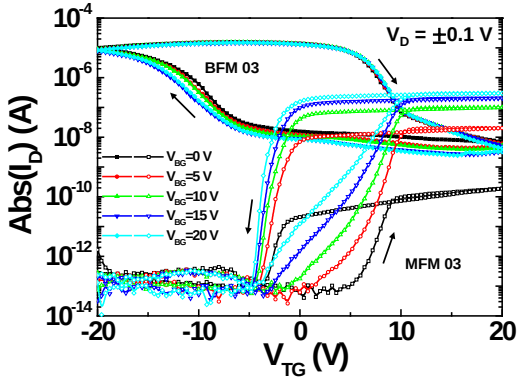


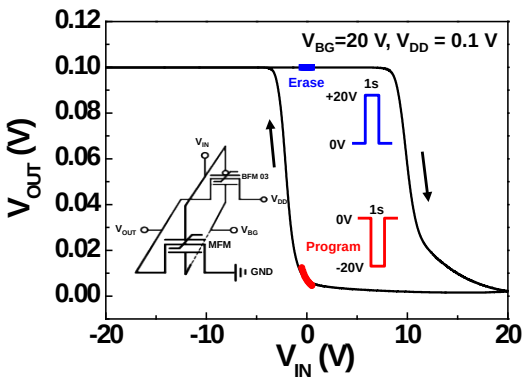
- *p*-BP and *n*-MoS_2 CMOS inverter circuit

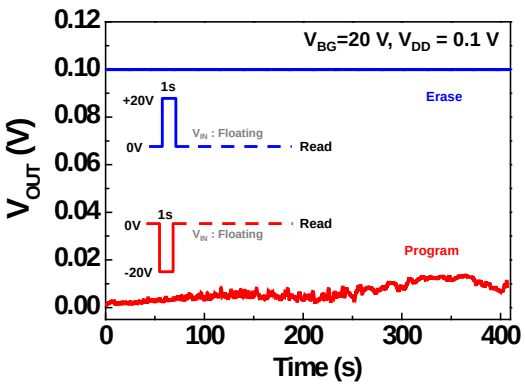












Y. T. Lee *et al*. ACS Nano DOI: 10.1021/acsnano.5b04592 (2015)

Summary

- We demonstrate the high performance MoS_2 based nonvolatile memory transistors

  ➔ High performance, clear memory window, proper dynamic and retention properties

  Papers: Y. T. Lee et al. Small 10, 2356 (2014) and J. Korean Phys. Soc Inpress (2015)

- We also demonstrate few-layered BP-based nonvolatile memory transistors and more advanced memory circuits.

  ➔ Unit device, resistive-load inverter, and CMOS inverter combined with MoS_2

  Paper: Y. T. Lee et al. ACS Nano DOI: 10.1021/acsnano.5b04592 (2015)