SAND2013-3220C

Nitride Memristors

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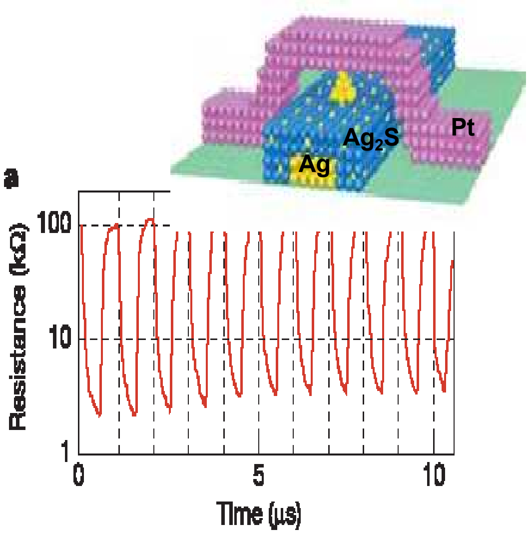
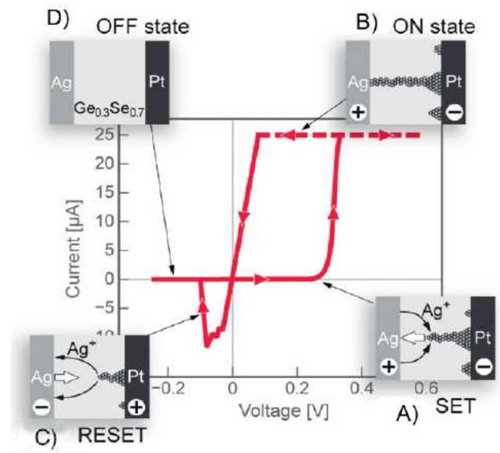
Outline

1. **Introduction and motivation**
2. **Device performance**
3. **Switching mechanism**
4. **Summary**

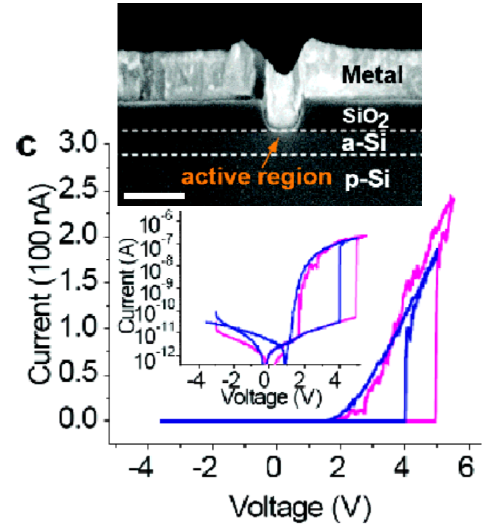
Introduction - switching materials



Terabe *et al*. Nature 433,47 (2005)



C. Schindler *et al*. '2007 NVMTS; AdvMat?



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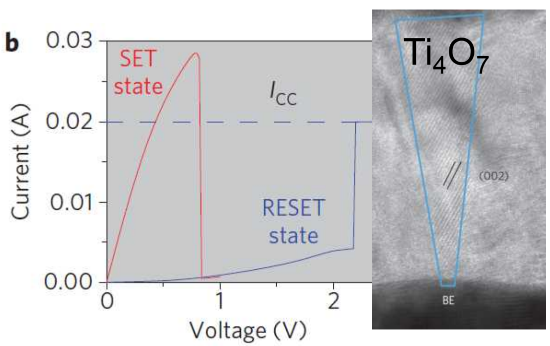
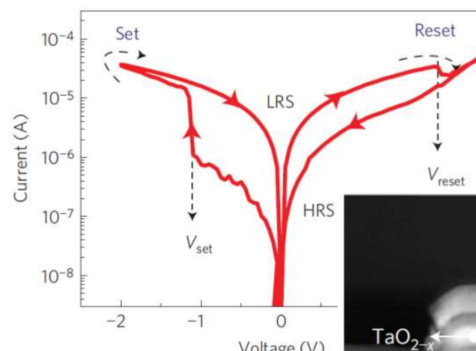
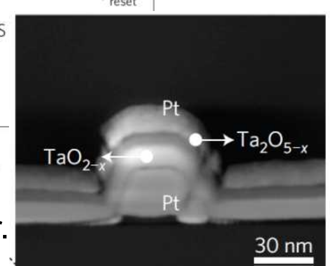
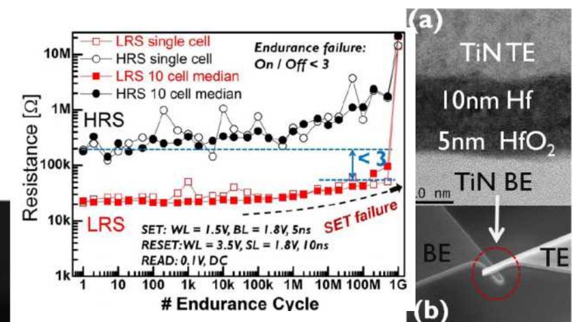


Kwon *et al*. Nature Nanotechnol. 5, 148 (2010)



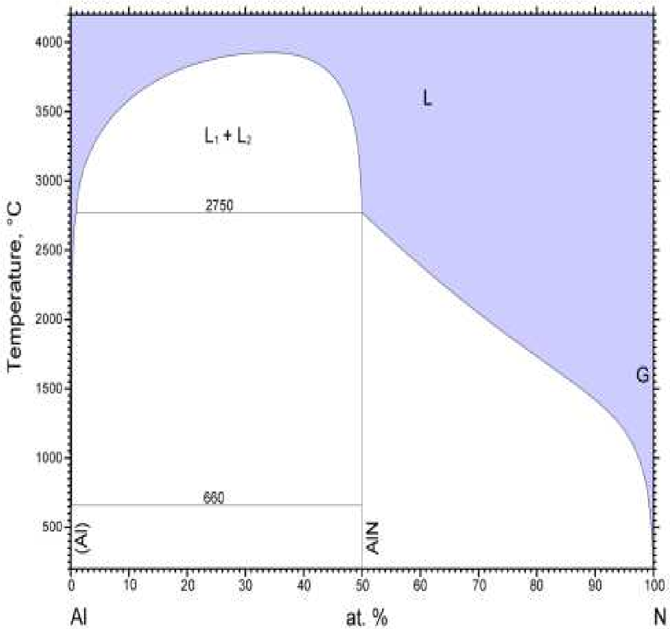


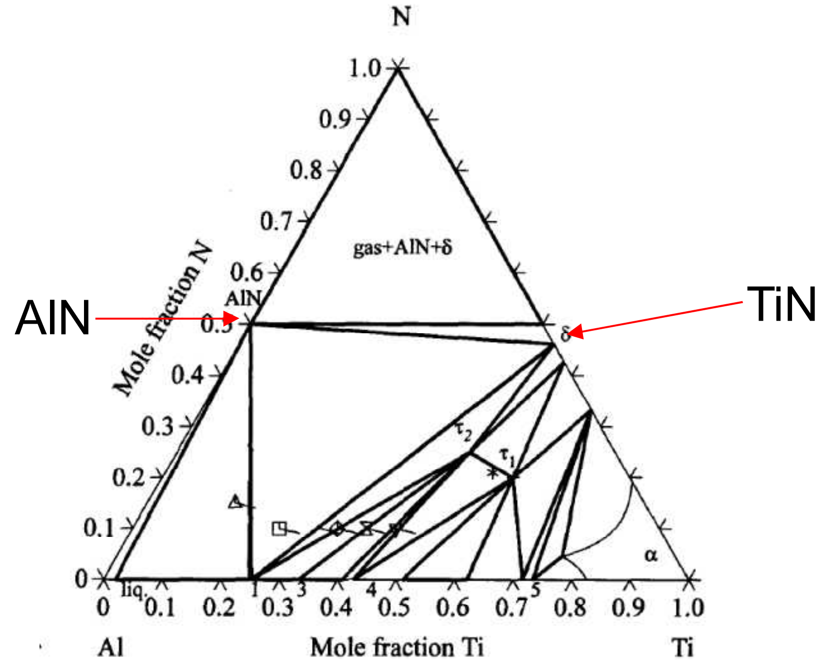
Lee *et al*. Nature Mater. 10, 625 (2011)



Chen *et al*. '2012 IEDM

MOTIVATIONS: A Full - nitride memristor





TiN/AlN structure

1) TiN: fab preferred material;

2) AlN and TiN: thermodynamic equilibrium between AlN and TiN

3) TiN: a large solubility of N → perfect electrode (serving as N reservoir)

4) AlN: only two stable solid phases →perfect switching material (a conducting phase + an insulting phase, same as Ta-O)

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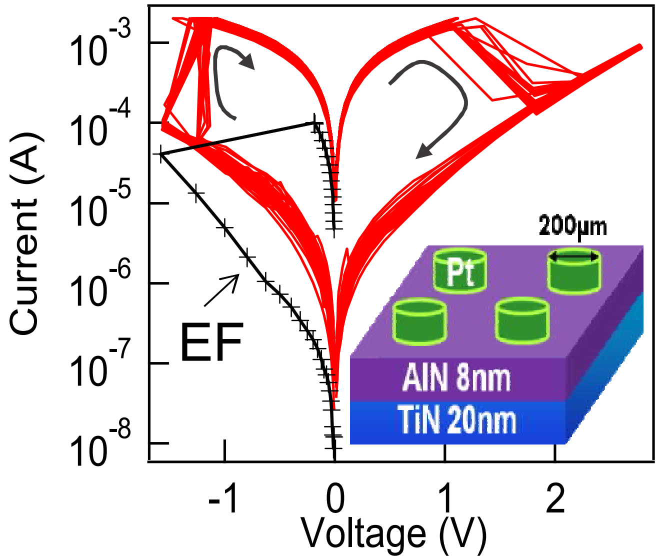
Device performance: forming-free, repeatable

AlN memristor

100 consecutive cycles

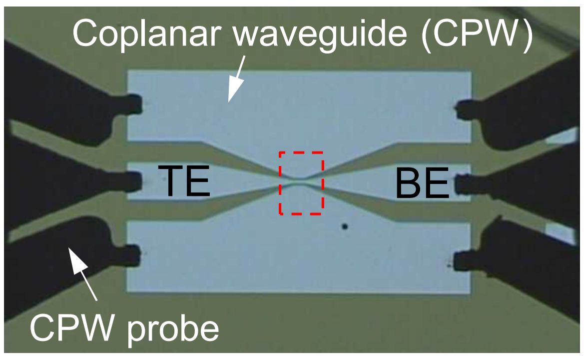


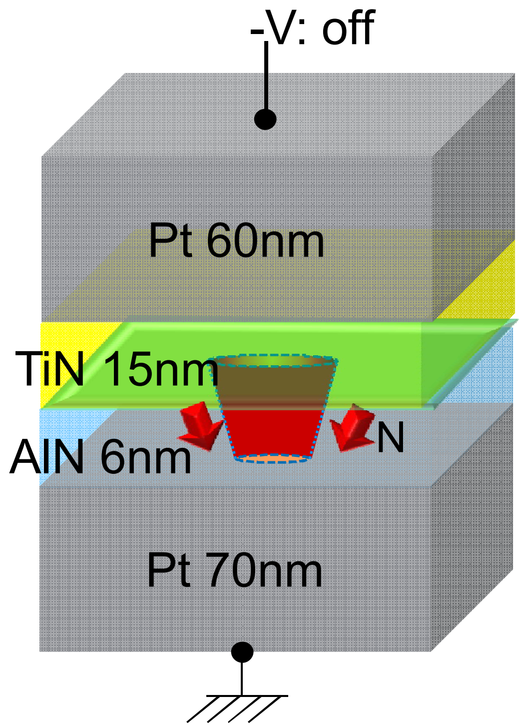
- Nitride memristors reported
- Stable and reproducible switching was observed after electro-forming
- Compliance current (I_{comp}) defines device resistance and I_{OFF}

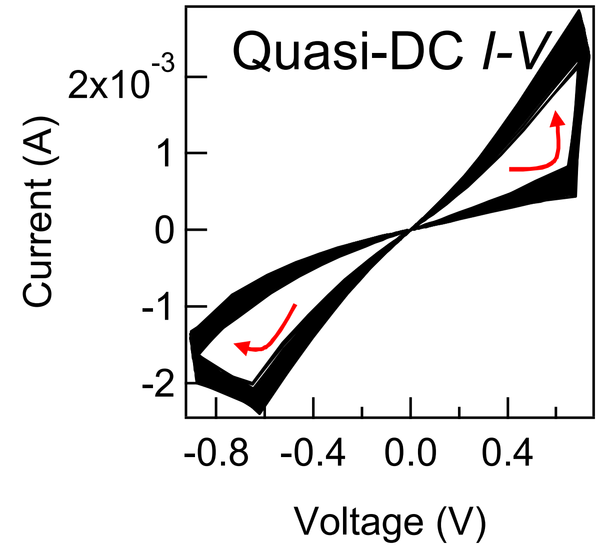
Choi *et al.* Appl. Phys. A Pagexx 2012

Device performance: Ultra-fast real-time switching

– Fabrication and characterization





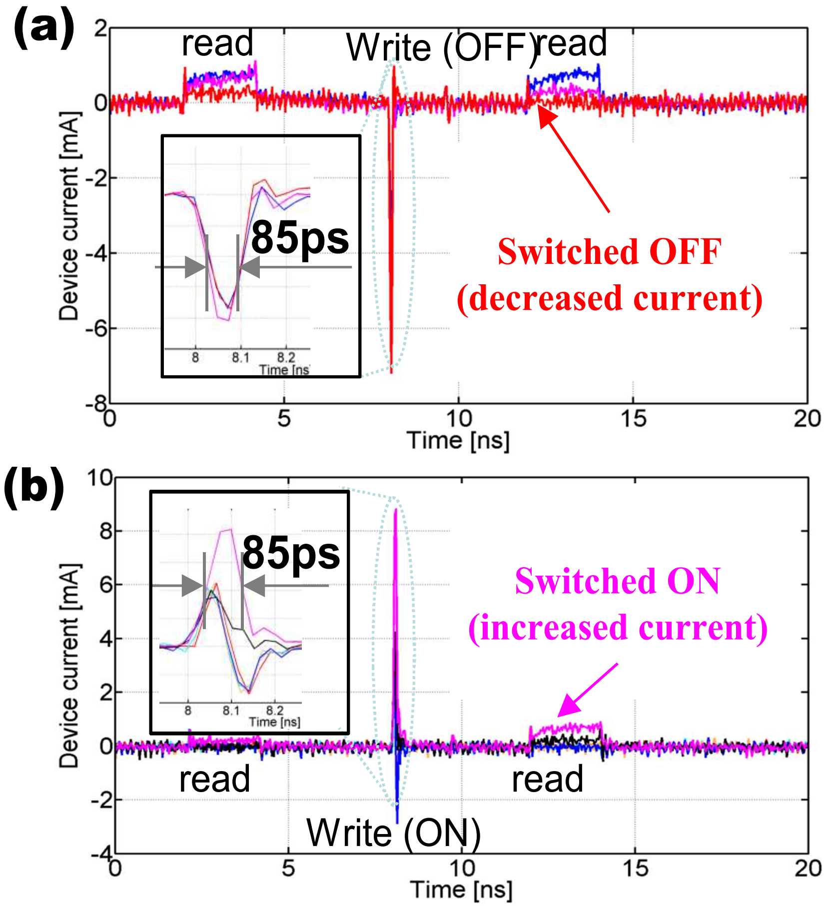


- High speed measurement setup employed (coplanar waveguide)
- *in-situ* monitoring of switching under sub-100ps FHWM pulse
- Switching seems to take place at the inert Pt/AlN interface

A. C. Torrezan *et al*. *Nanotechnology* 22, 485203 (2011)

Device performance: Ultra-fast real-time switching

Bipolar device (2μm x 2μm) – OFF & ON switching

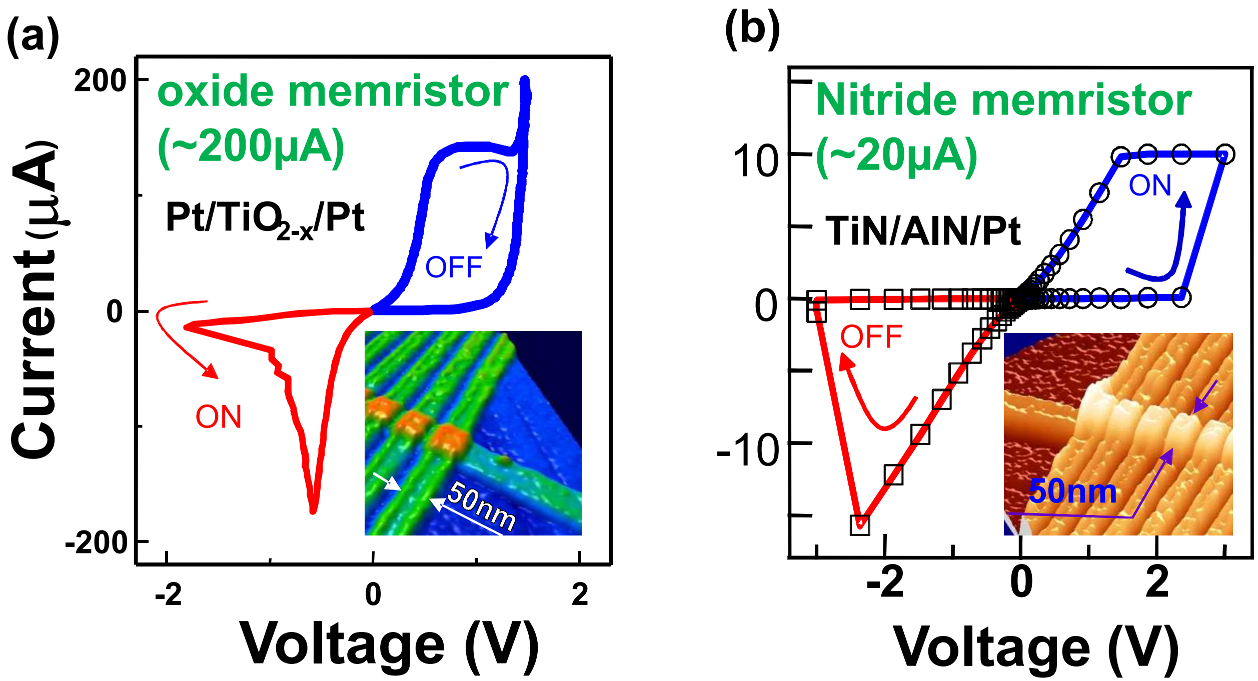


Pulse sequence	Quasi-DC device resistance [kΩ]
Initial	0.73
#3 (-2.0 V / 86 ps)	97.83 (OFF)
Initial	83 MΩ
#6 (+2.1 V / 87 ps)	2.56 kΩ (ON)
#7 (+2.1 V / 87 ps)	0.73 kΩ (ON)

- Sub-100ps switching observed in nitride memristor
- Strongly nonlinear switching kinetics (shorter time - higher voltage)

Device performance: scalability and low energy

50nm x 50nm nanodevice



Low-energy device:
Lower current than TiOx and even TaOx

- Nano-scaled device fabricated using 50nm half-pitch Nano-imprint template
- OFF-switching current reduced to 10~20 µA (lower than TiOx and TaOx)
- High ON/OFF ratio (>100)

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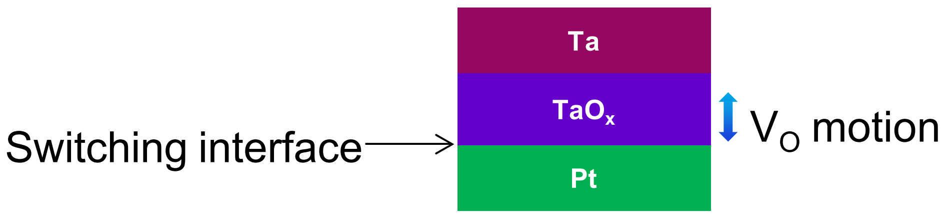
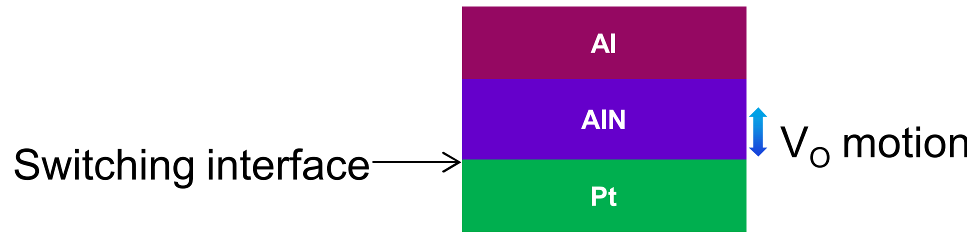
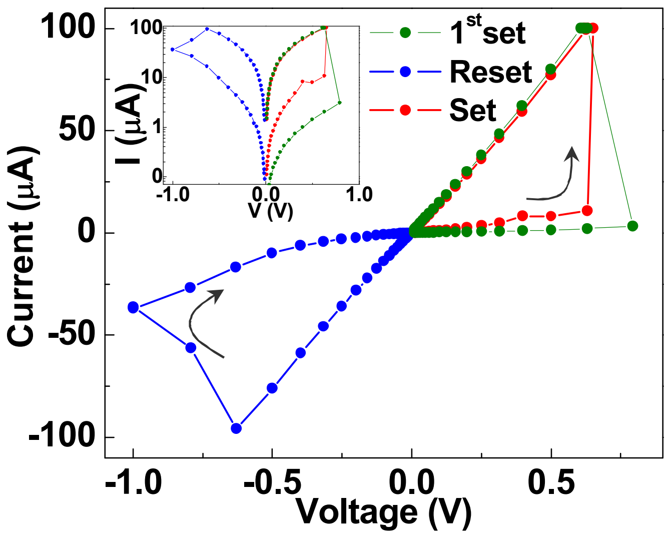
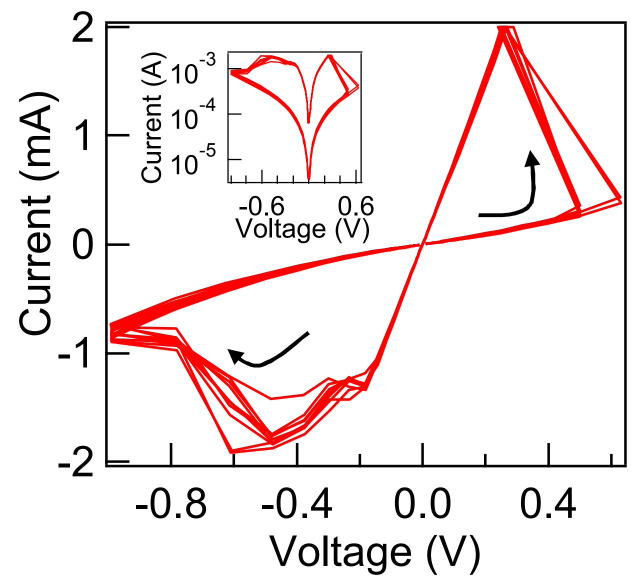
Switching mechanism: analogue of oxide switches

– Switchable interface? More inert interface favorable!



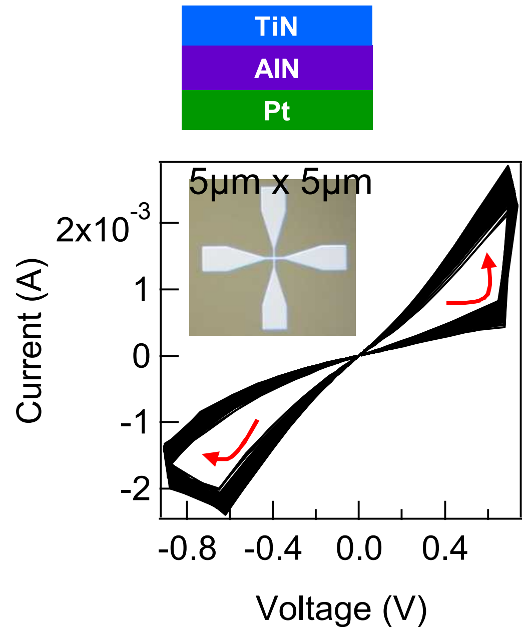


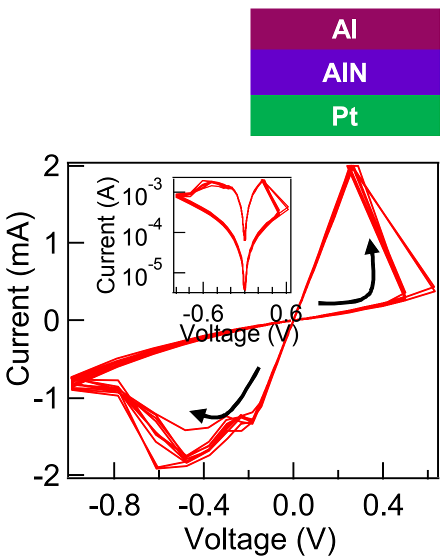


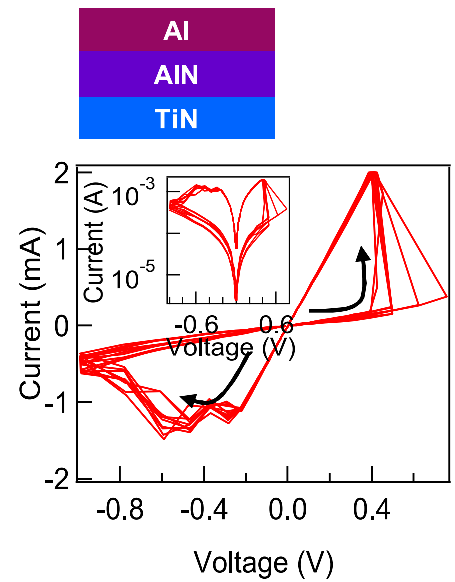


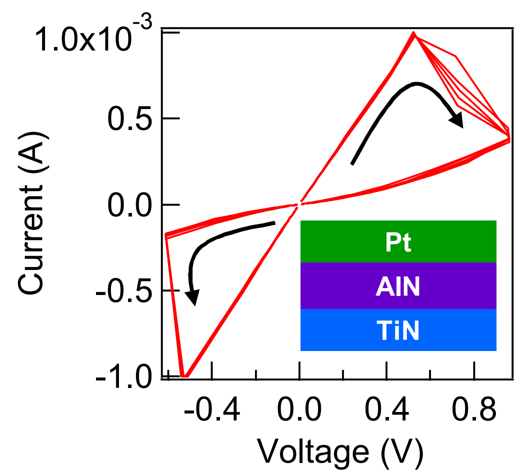
Switching mechanism: Switching polarity

– Switchable interface? More inert interface favorable!







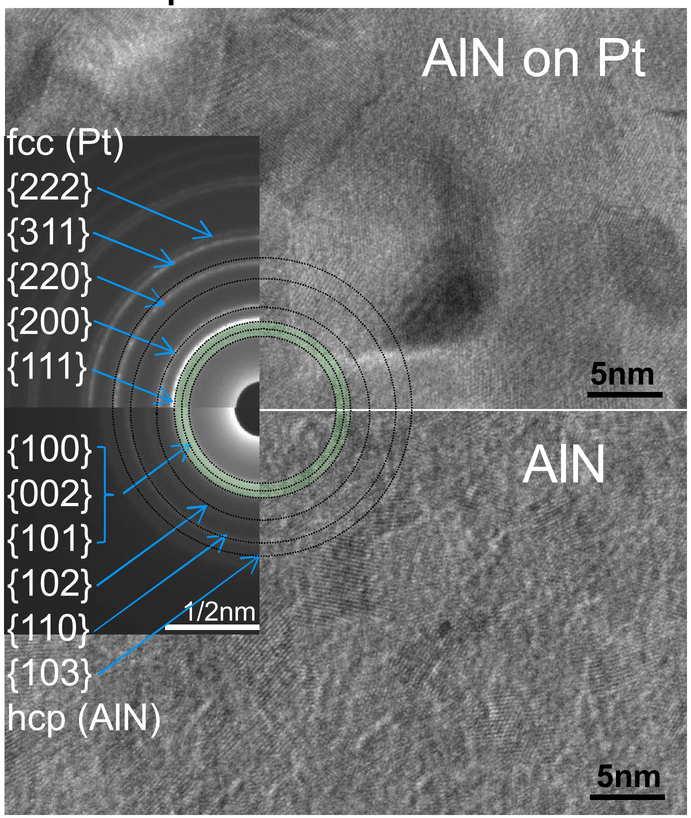


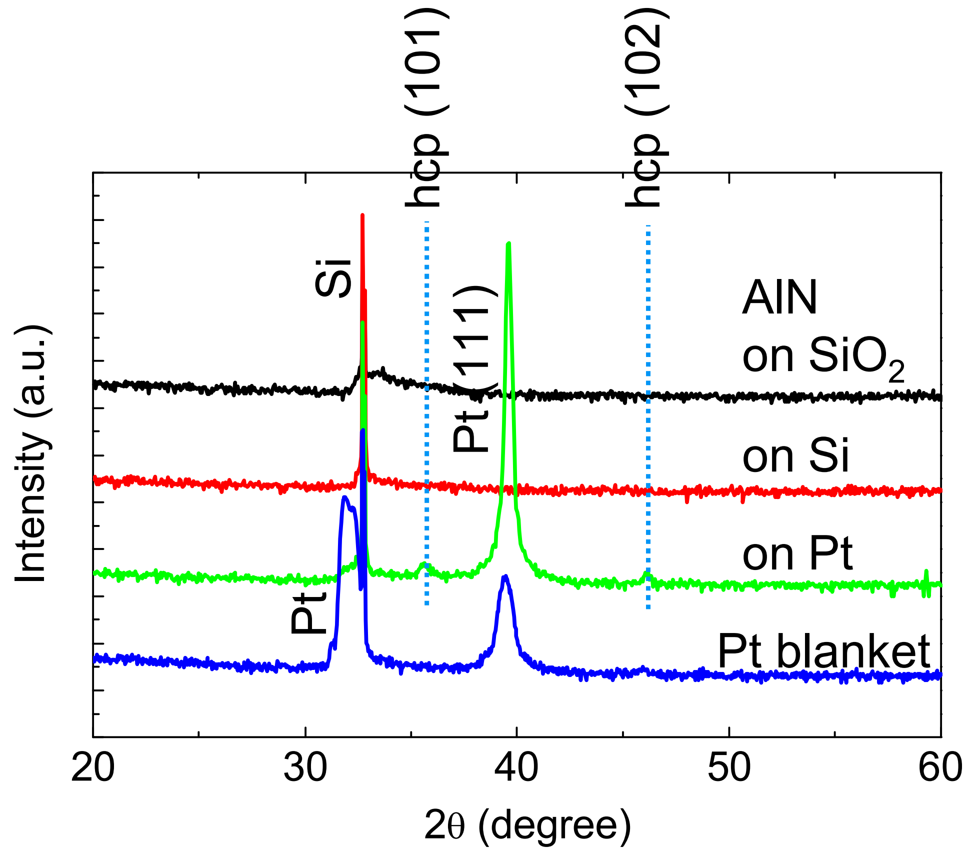
Questions:
Another oxide switch
or real nitride switch?!

Switching mechanism: film structure

AlN films grown by ALD

plan-view TEM

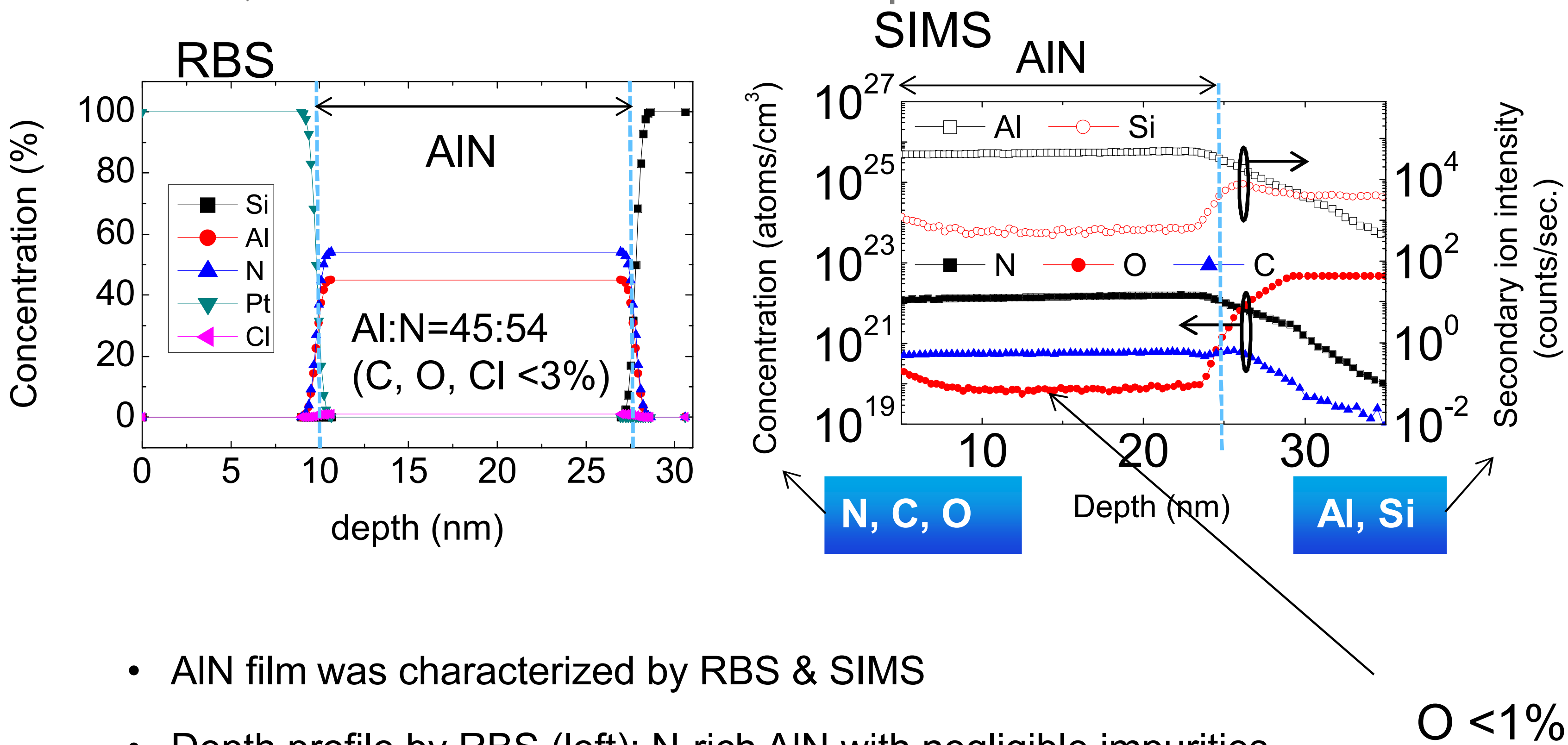




- XRD amorphous matrix with fine nano-crystalline (hexagonal wurtzite) phases observed by TEM

Switching mechanism: film composition
Integrity of nitride film

RBS & SIMS; atomic concentration and impurities

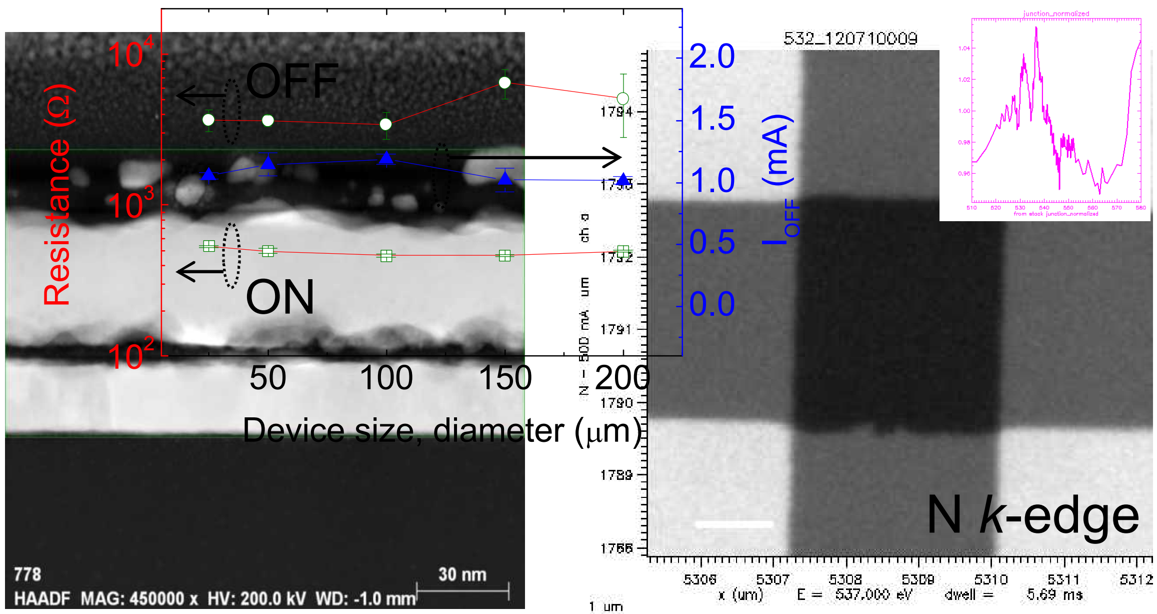


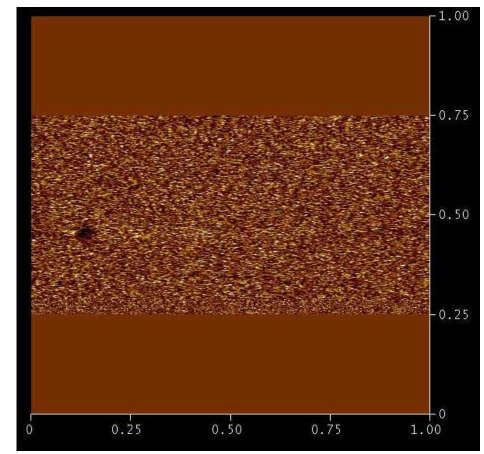
- AlN film was characterized by RBS & SIMS
- Depth profile by RBS (left): N-rich AlN with negligible impurities
- Depth profile by SIMS (right): uniform Al & N profiles with much lower C & O concentration
- Highly uniform and pure AlN film was grown by ALD method

Switching mechanism: localized channels

– Various *ex-situ* method

I_{ON} = 1.0 mA fixed





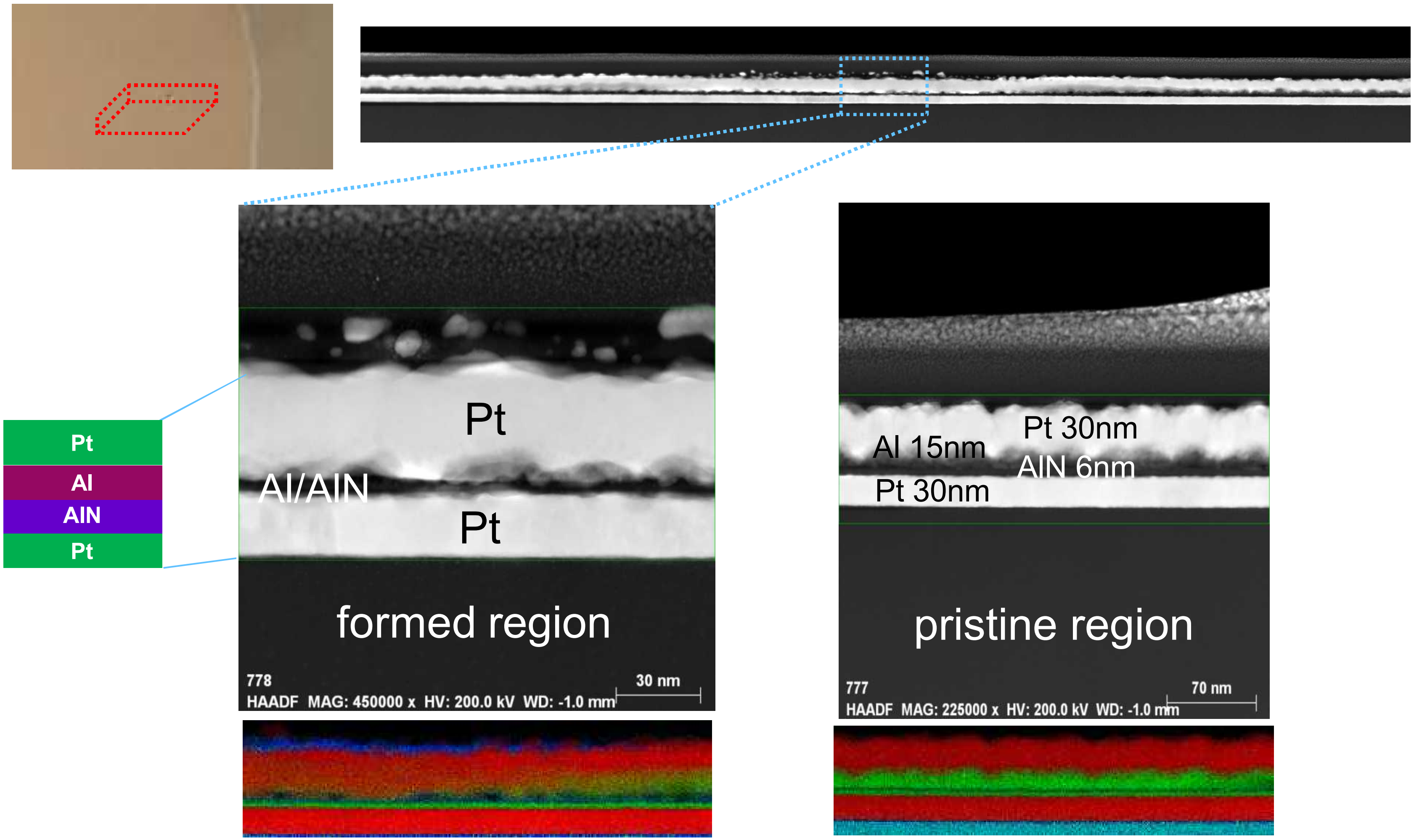
Focused Ion Beam -Transmission Electron Microscopy (FIB-TEM)

Scanning Tunneling X-ray Microscopy (STXM)

Pressure Modulated Conducting Microscopy (PMCM)

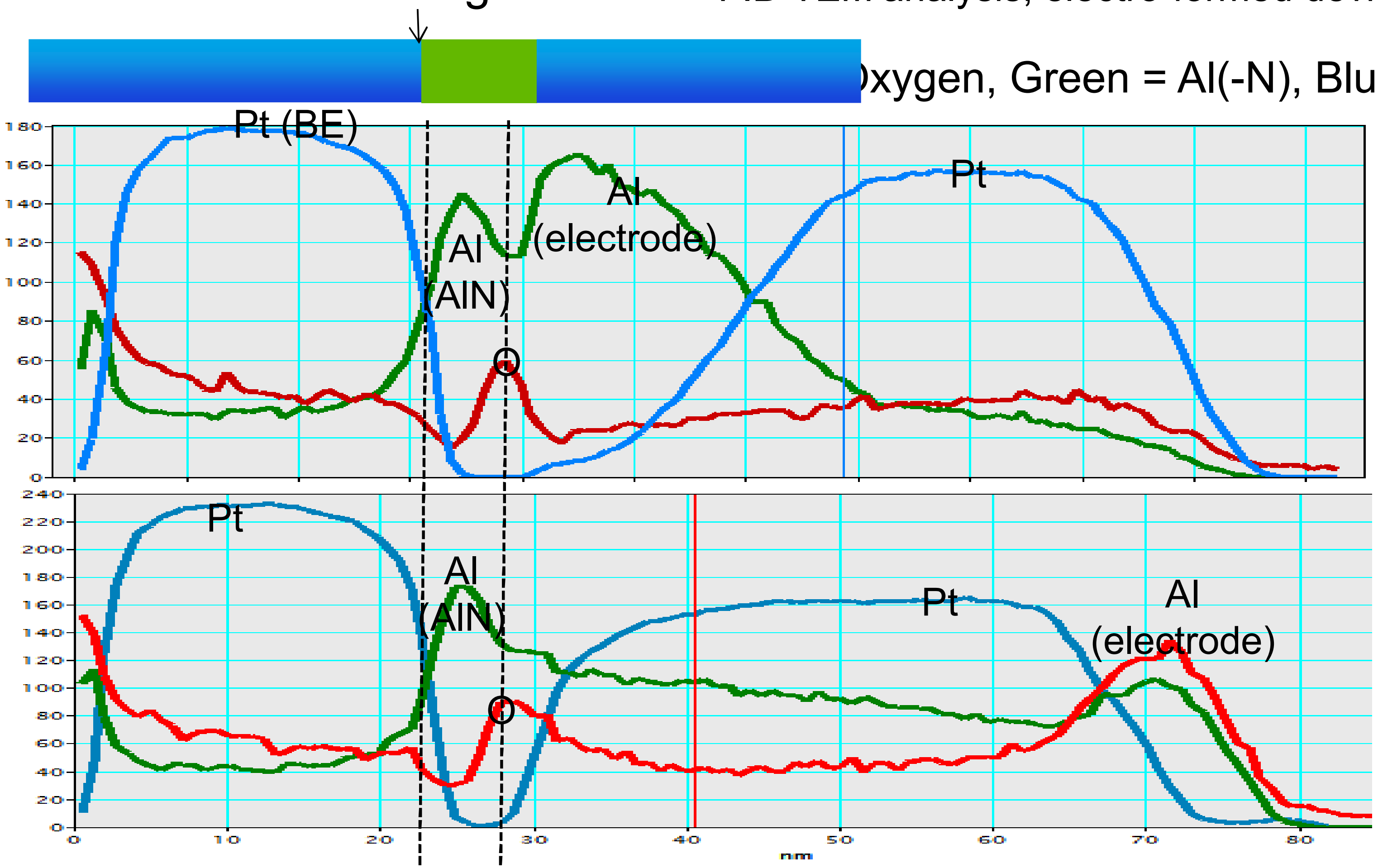
Switching mechanism: anatomy of active region

FIB-TEM analysis; electro-formed device



Switching mechanism: O-free switching interface

Switching interface FIB-TEM analysis; electro-formed device



)xygen, Green = Al(-N), Blue = Pt

- Strong heating expected from intermixing between top metals (Al/Pt)
- The Pt(BE)/AlN remains O-free → switching from a Pt(BE)/Al-N interface
- Chemical changes of Al-N around channel region are under investigating

Summary

– *Nitride memristors*

- Nitride memristors were fabricated and characterized from materials to devices
- AlN films grown by ALD are N-rich with uniform depth profile, much lower concentration of C, O impurities
- Switching seems to take place at the more inert interface, such as Pt/AlN or TiN/AlN
- FIB-TEM analysis revealed that Pt/AlN switching interface is preserved from O contamination in spite of significant heating during electroforming
- Fast switching (FWHM ~85ps) for both ON and OFF was observed
- Nano-devices were fabricated and reversible switching with high ON/OFF (>100) ratio and low current (~10uA) operation was observed
- Nitride memristors can have a great potential and open a new materials pool

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