'TORAY'
Innovation by Chemistry

Three-Dimensional Structural and Compositional Analysis of MTJ by STEM/EDX Tomography

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INNOVATION IN EXCELLENCE UP

Agenda

1. Introduction
   - MTJ (Multi Tunnel Junction)
   - Morphological approach to characterization
   (2D)TEM, 3D-TEM(HAADF-STEM, EDX)

2. Experimental
   - MRAM structure
   - Sample preparation for 3D
   - HAADF STEM Tomography
   - EDX Tomography

3. Results and Discussion

4. Conclusion

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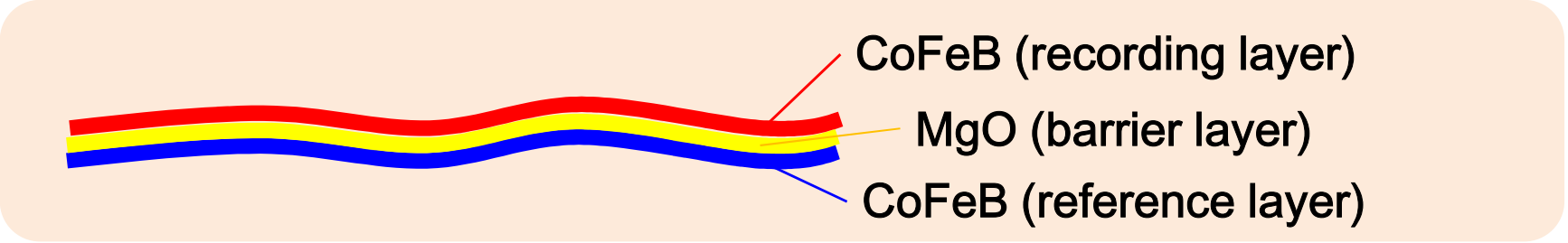
Introduction

MTJ (Multi Tunnel Junction) structure



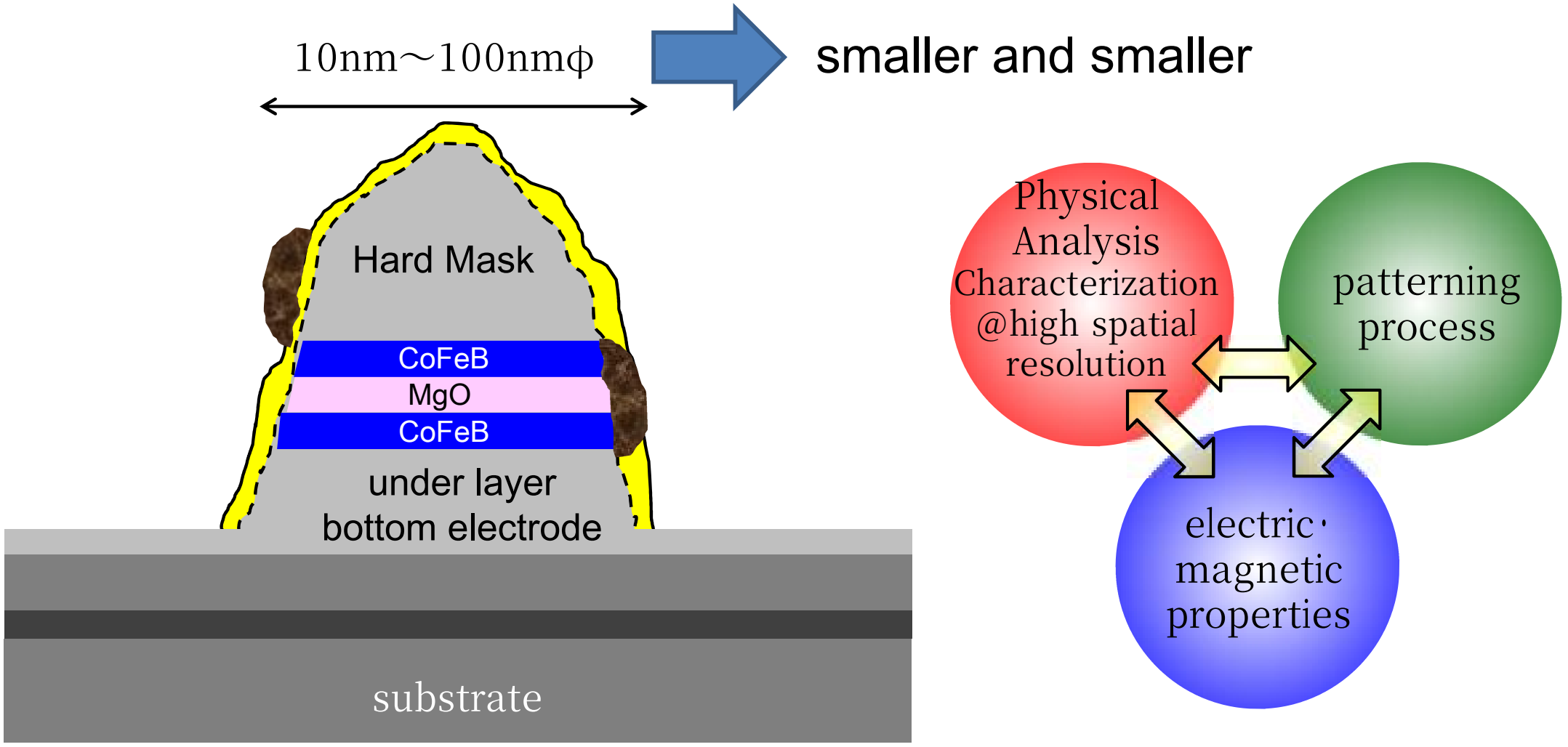
High speed and Low power consumption

MRAM (Magnetic Random Access Memory) is greatly expected to be replaced to conventional volatile cache memory.

To minimize the size of MRAM, there are several problems such as downscaling, etching damage by the patterning process.

Characterization of interface roughness etc. are very important.

MRAM structure and subjects

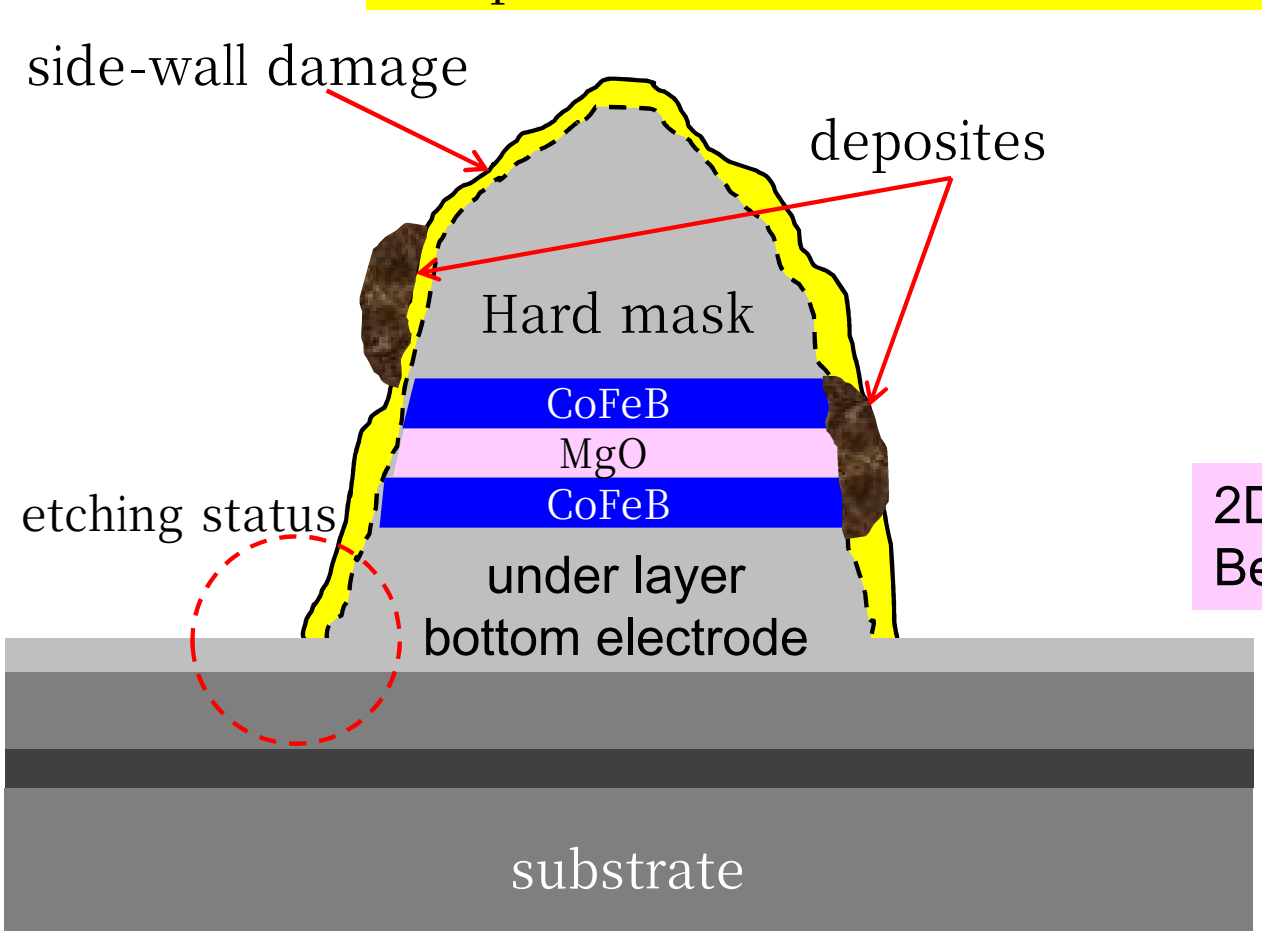


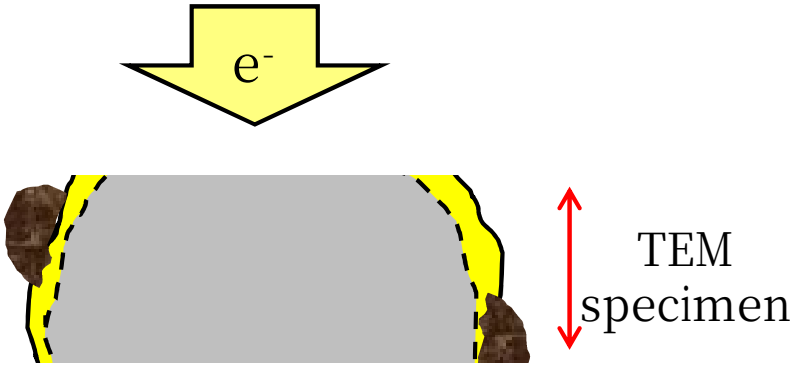
TEM is the key tool for MTJ devices

Attention points of MRAM characterization by TEM/STEM, EDX, EELS

Subjects

total device size
device shape
roughness of each layer
composition and diffusion status

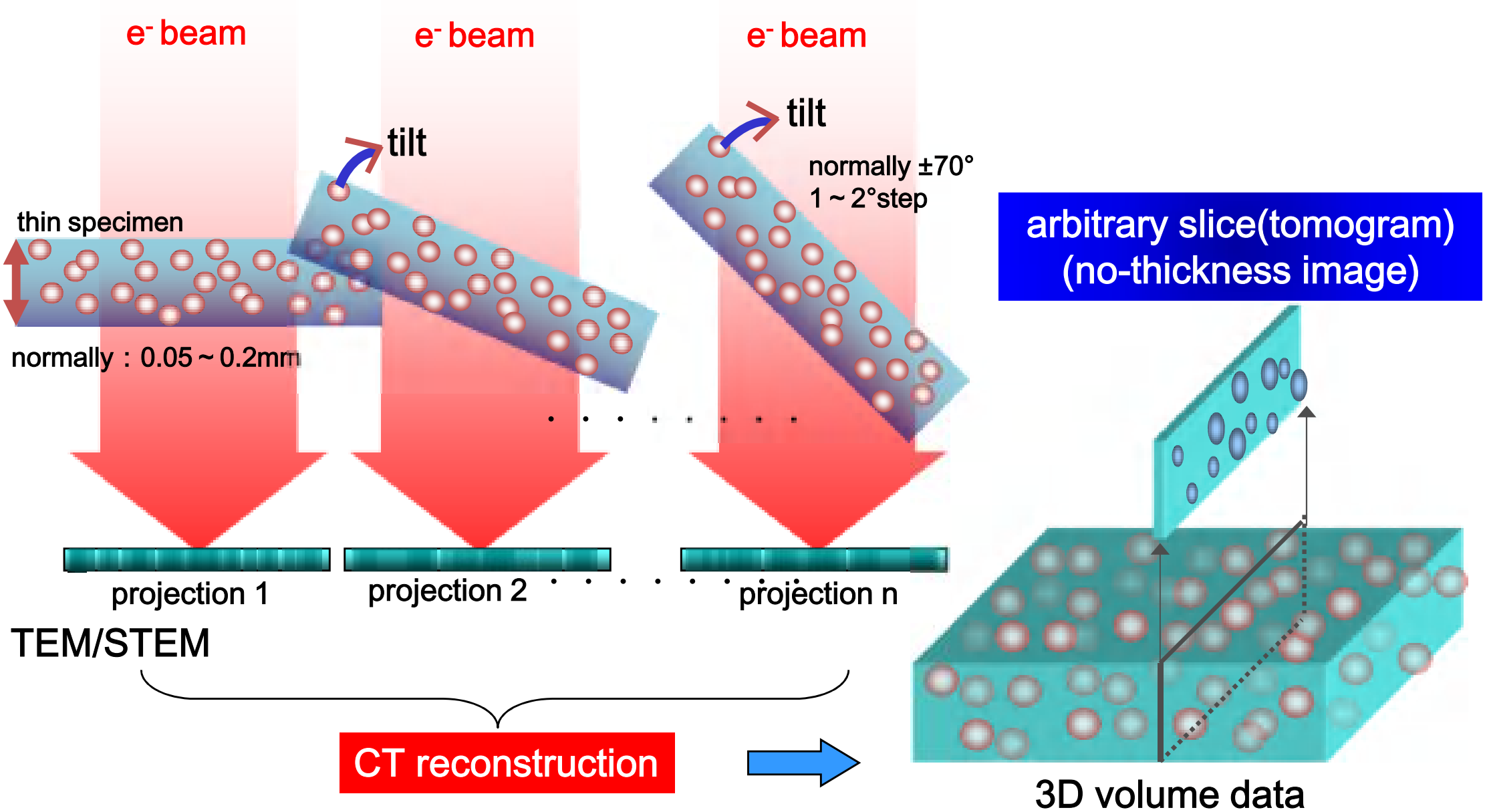




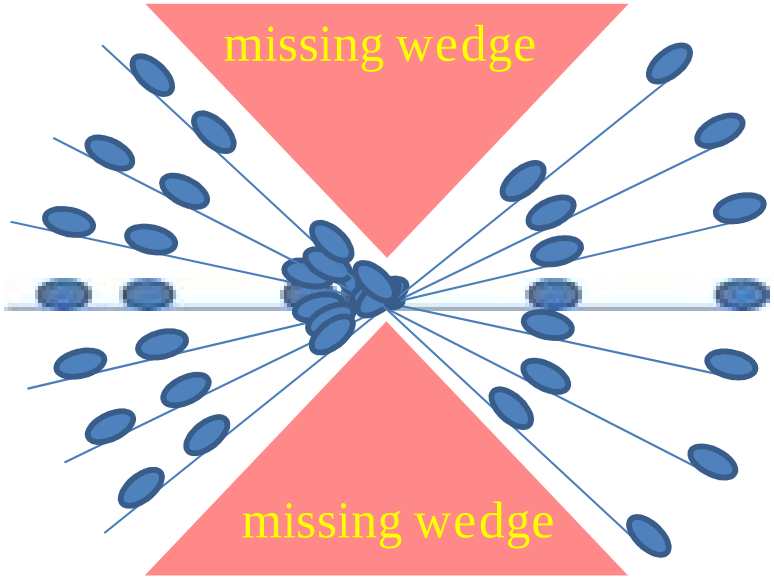
2D-TEM approach is inperfect
Because information might be overlapped

3D approaches will be needed!

Schematic diagram of TEM tomography



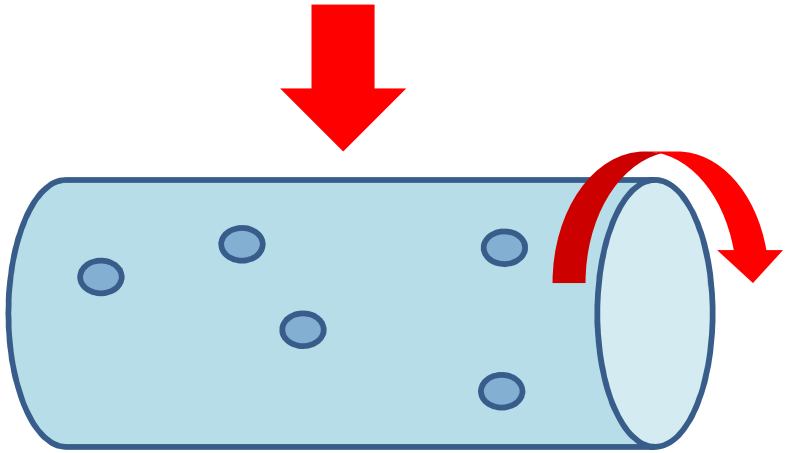
To overcome TEMT resolution problem



conventional thin specimen

Normal thin specimen
limits the tilting angle to +/-70 deg..

“Missing wedge” zone degrades resolution.



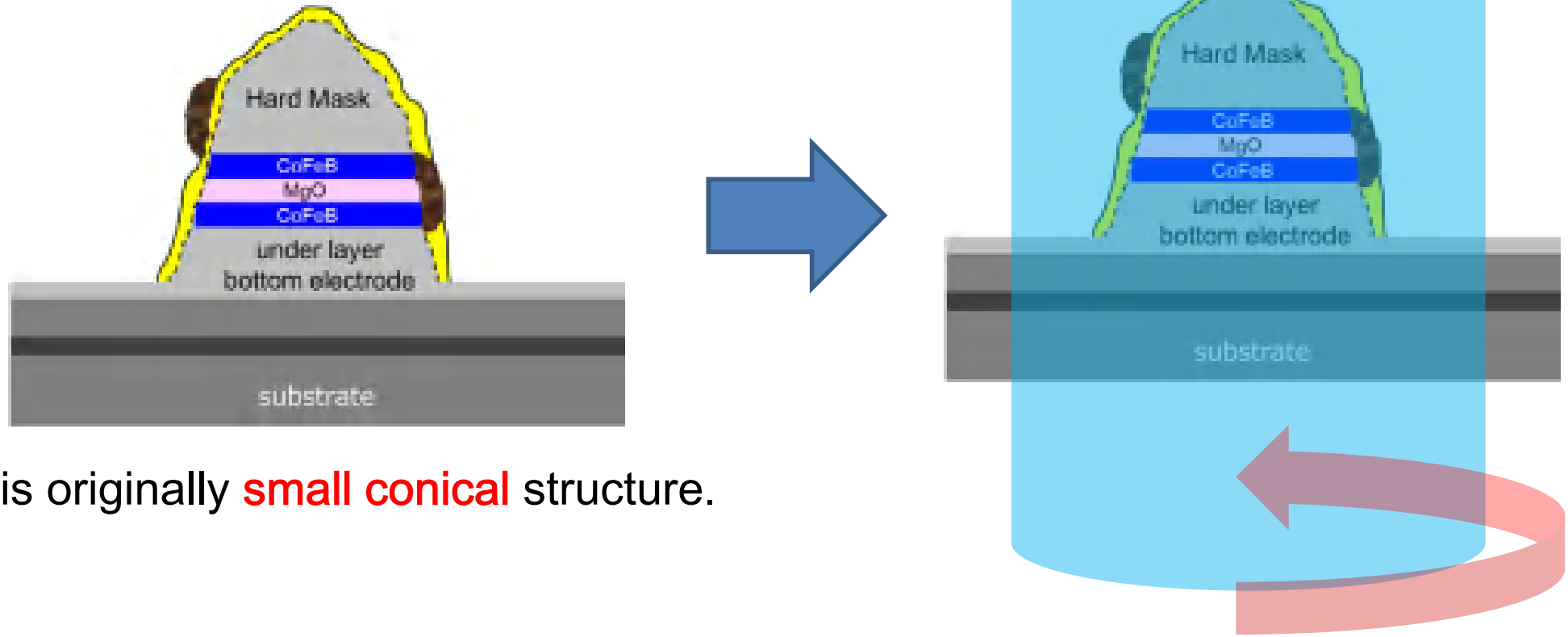
Rod-shape specimen
allows tilting angle to +/-90 deg..

No “Missing wedge”

(Kawase et al.,Ultramicroscopy. 2007 Jan;107(1):8-15.)

TEMT approaches for MRAM

Think about MRAM device structure…



It is originally small conical structure.

We aim to get whole information of MRAM by rod-shape TEMT

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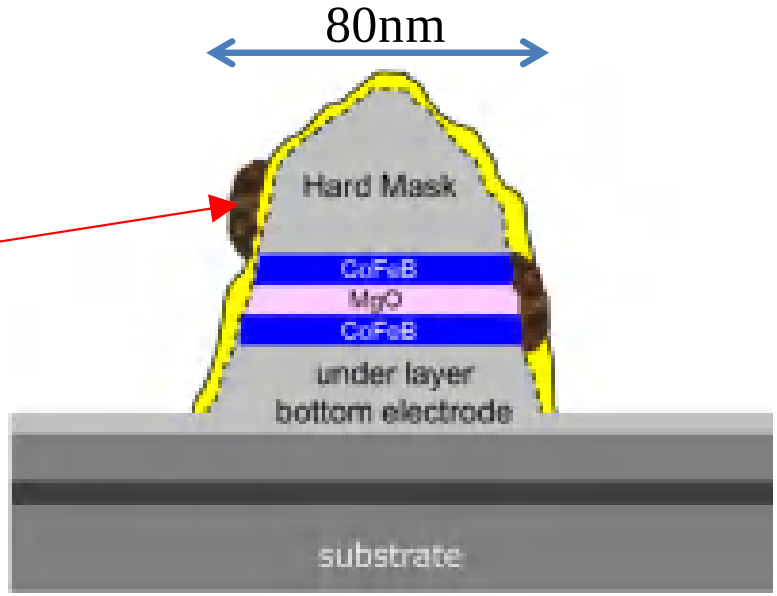
Sample and experimental

Sample : 80nmϕ MTJ (MRAM) device model
double junction sructure
prepared by Tohoku univ. (CIES)



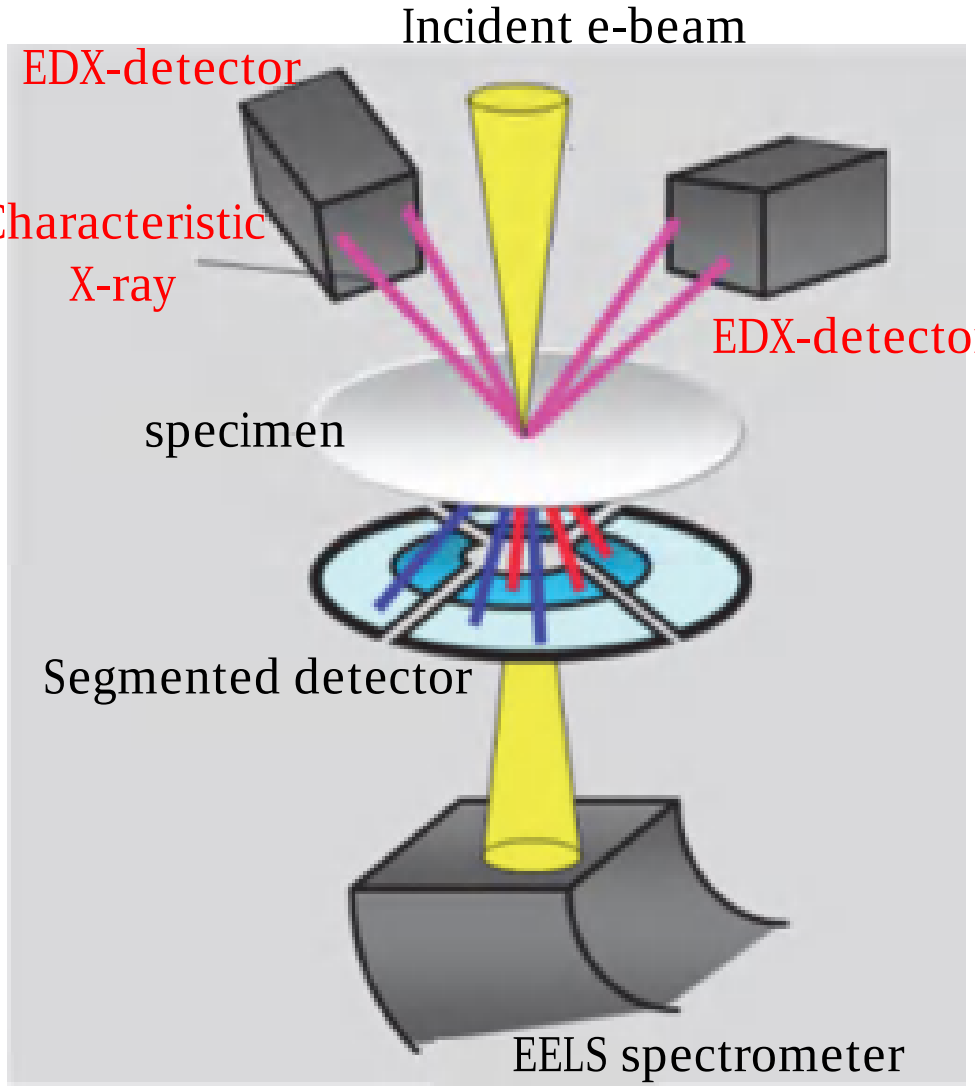
Deposits were remained by intent for feasibility study .

apparatus :

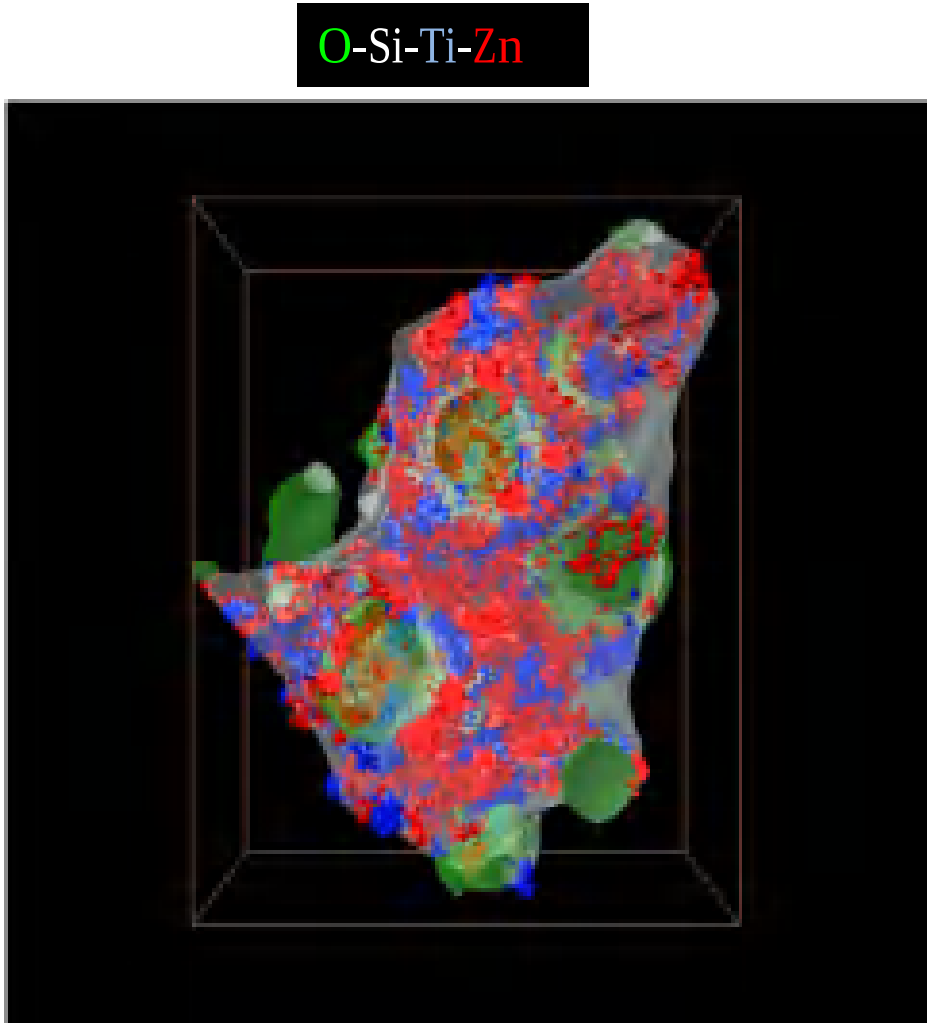
◇FIB: Thermo-Fischer Helios 660 (SEM/FIB dual beam)

◇STEM: JEOL JEM-ARM200F Dual-X (Cs-corrected STEM/double EDX detector)
software : TEMography (SiF)

EDX tomography



Example : sunscreen creme @-170℃



20nm

Inamoto, 2017

Dual detector greatly improved EDX efficiency

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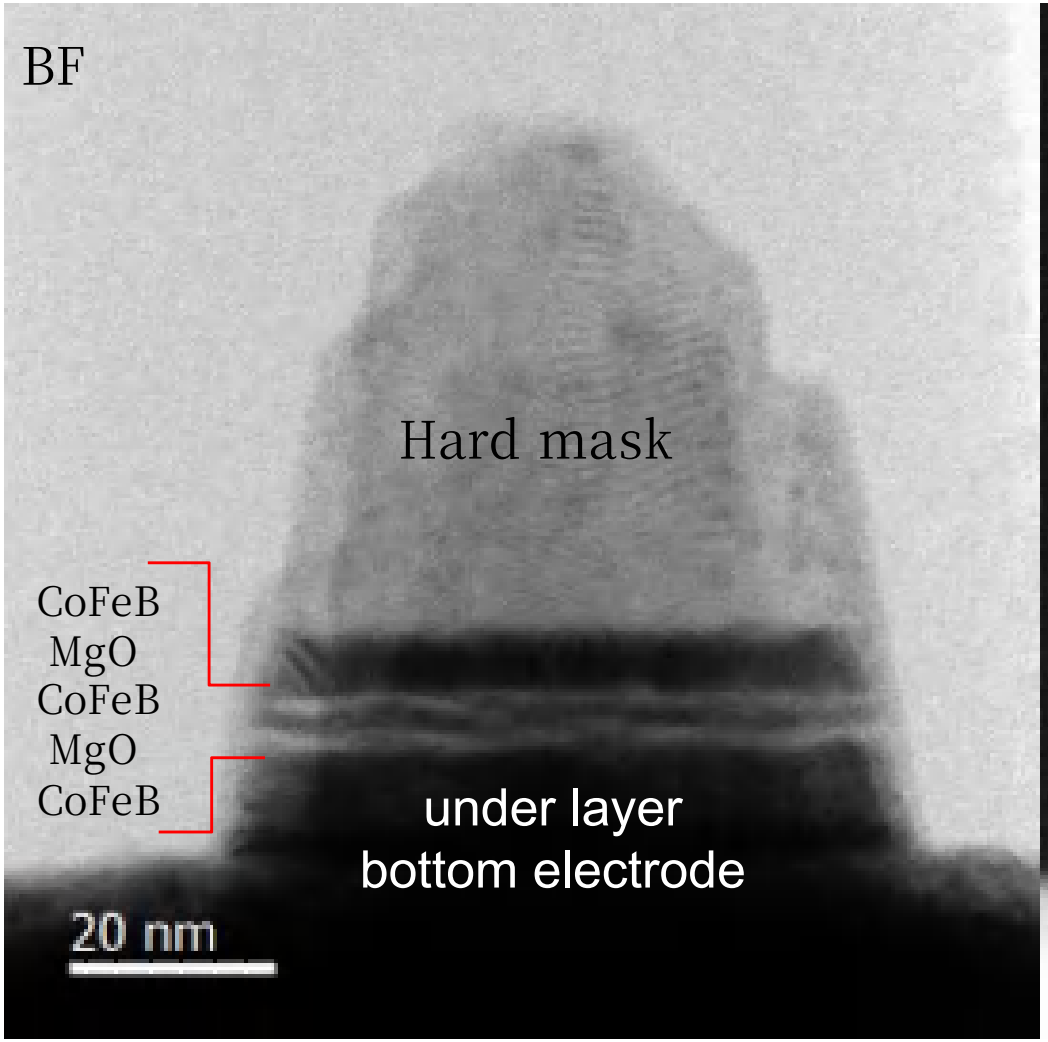
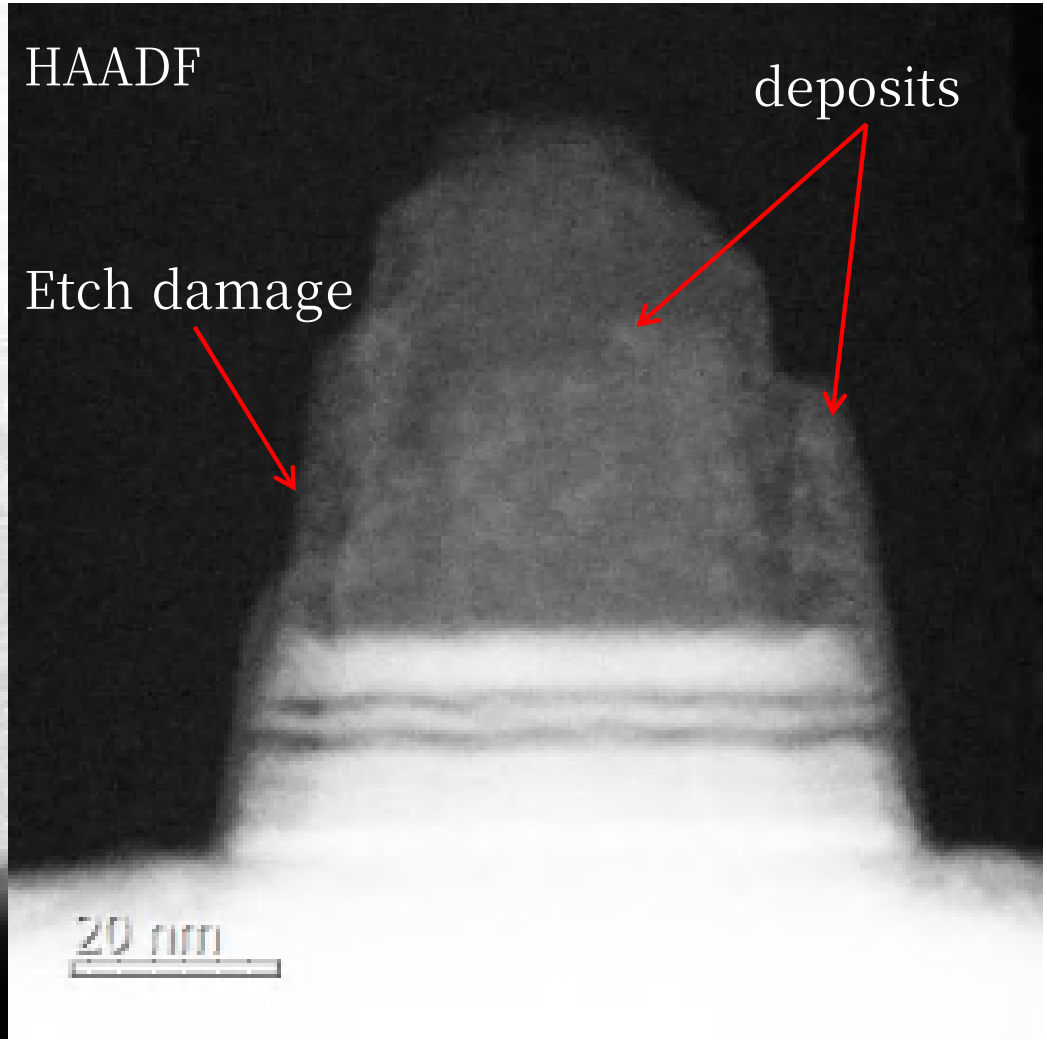
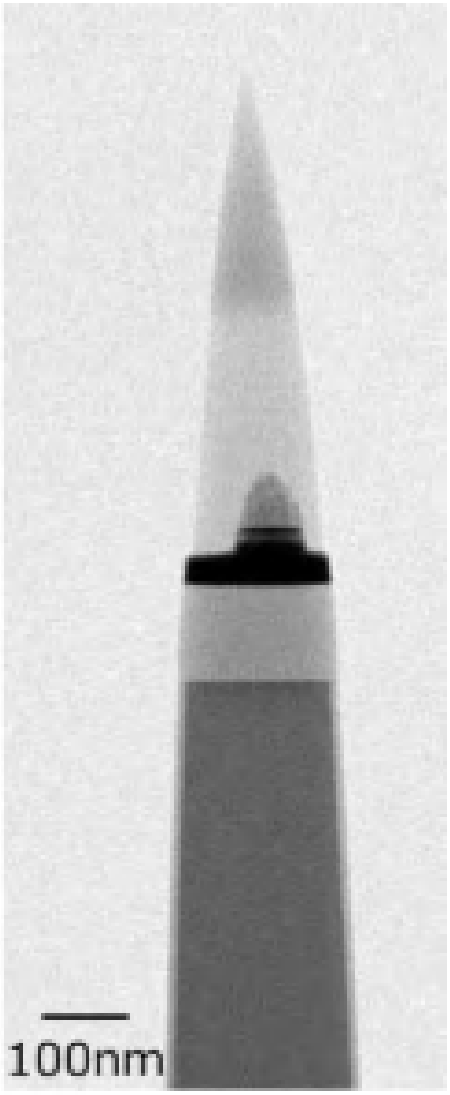
2D STEM observation



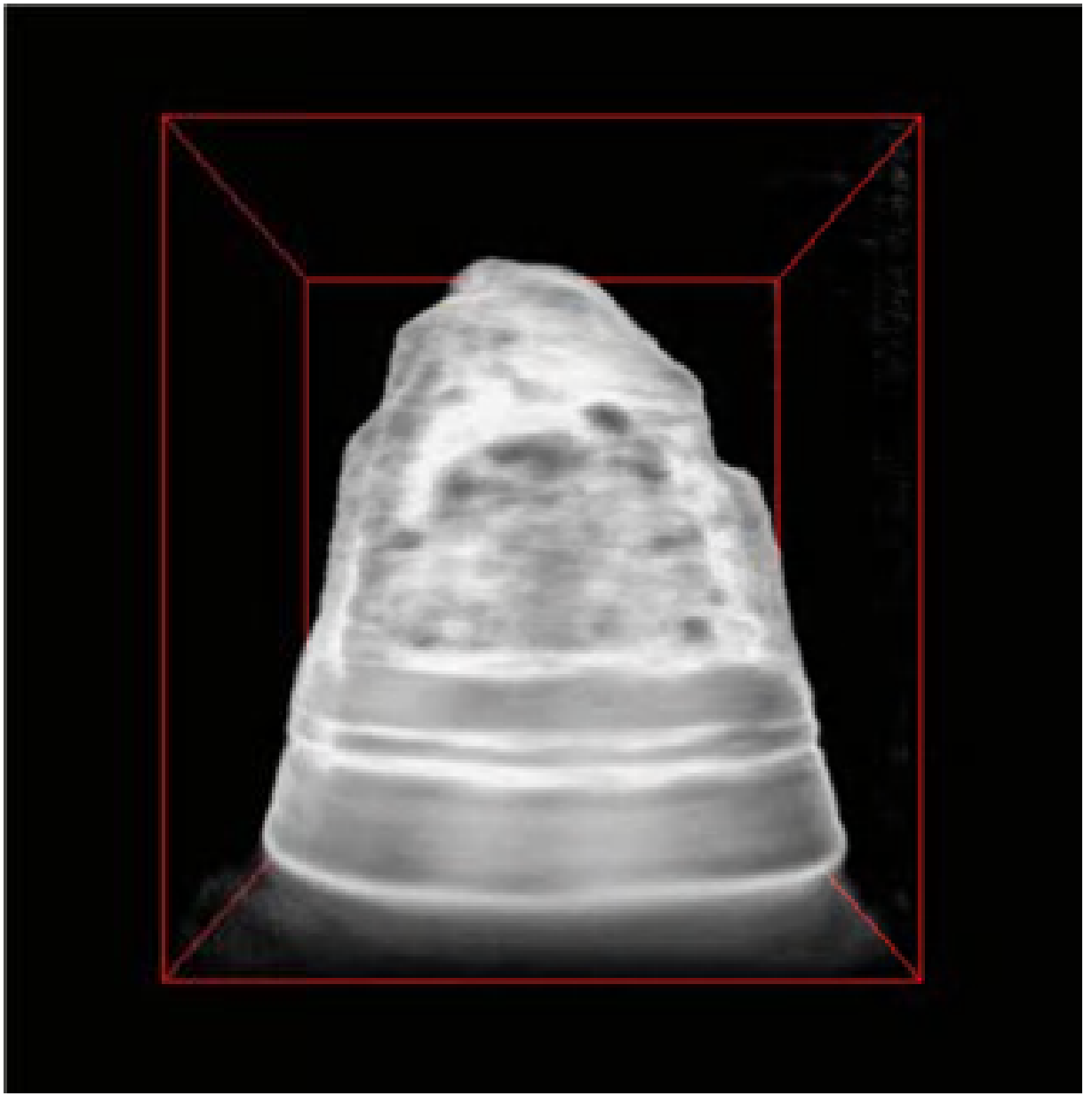


MTJ(double junction) structure and deposits have been observed, but 2D projection is not so clear. ⇒ 3D

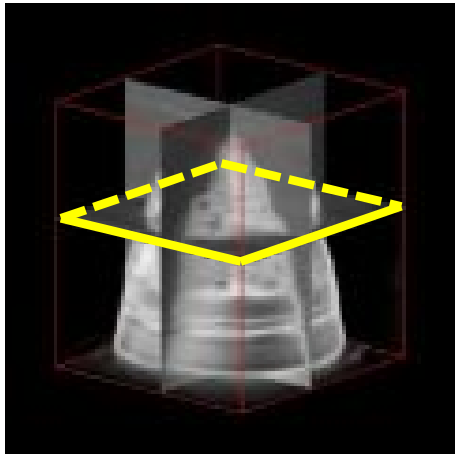
HAADF 3D STEM

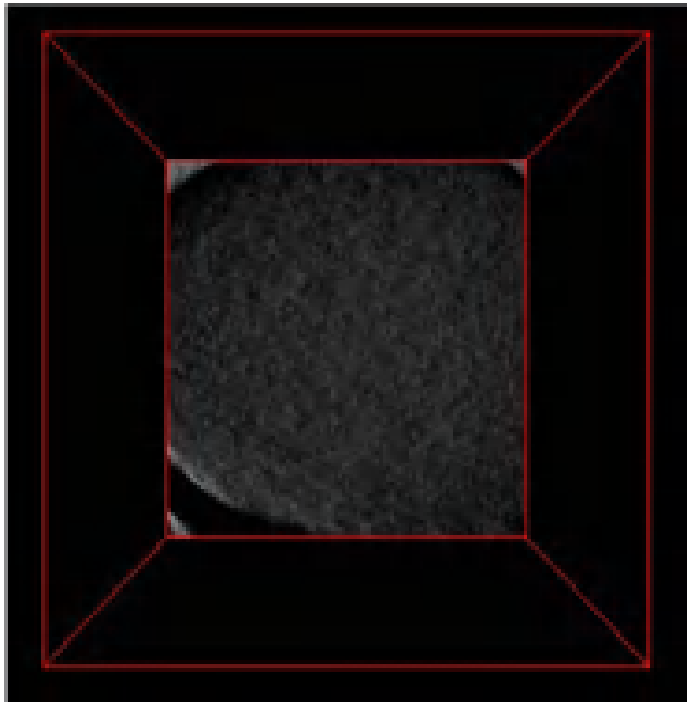


Rod-shape specimen by FIB

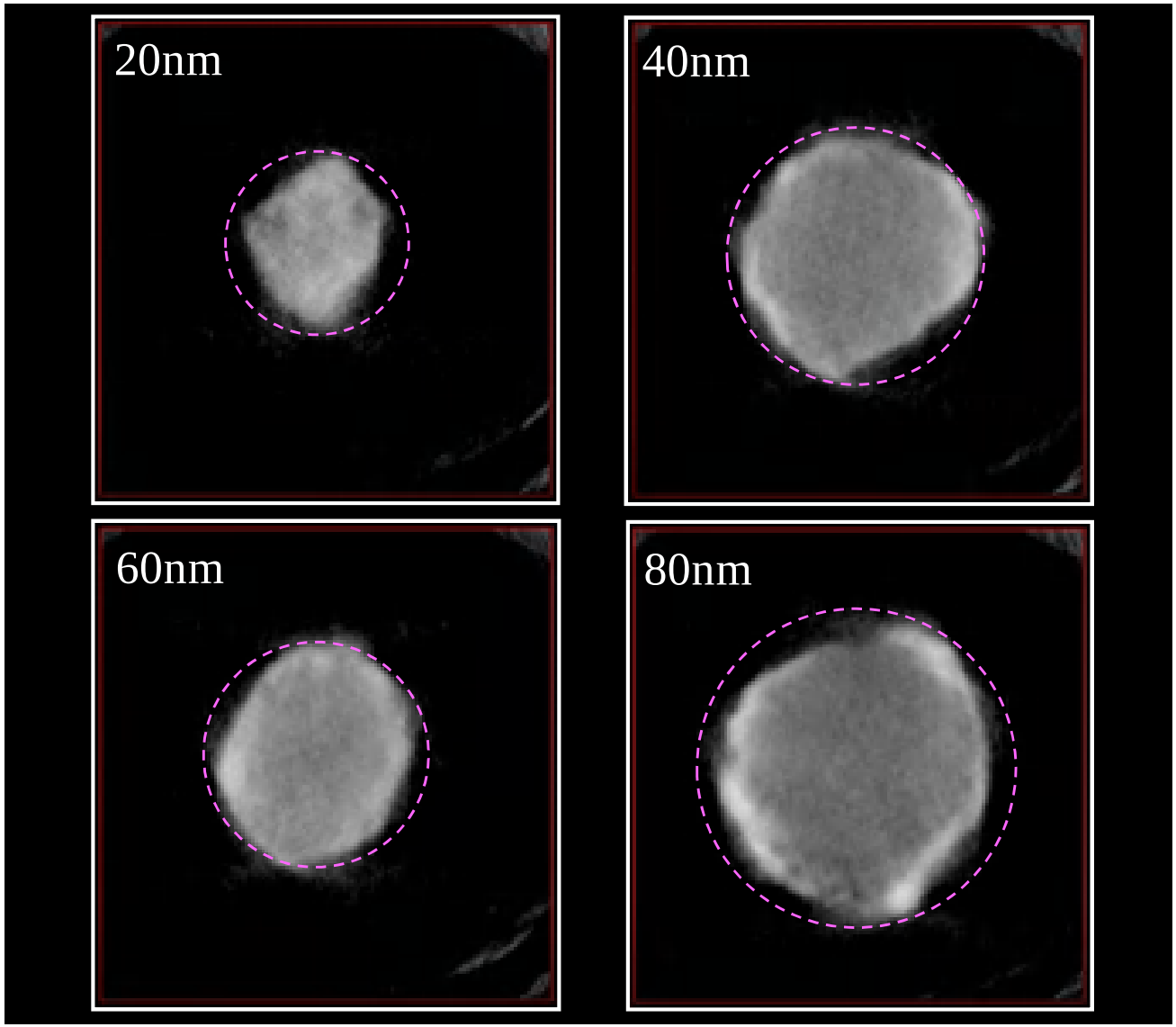


Tomogram series : from Top to Bottom



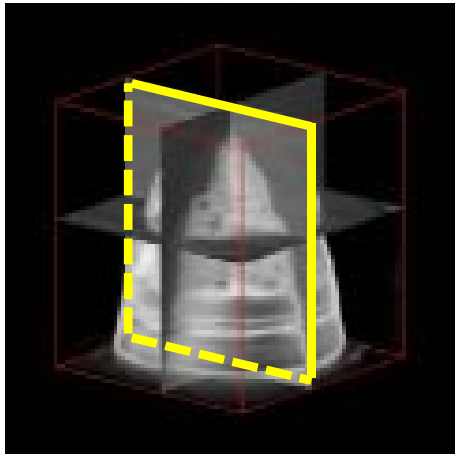


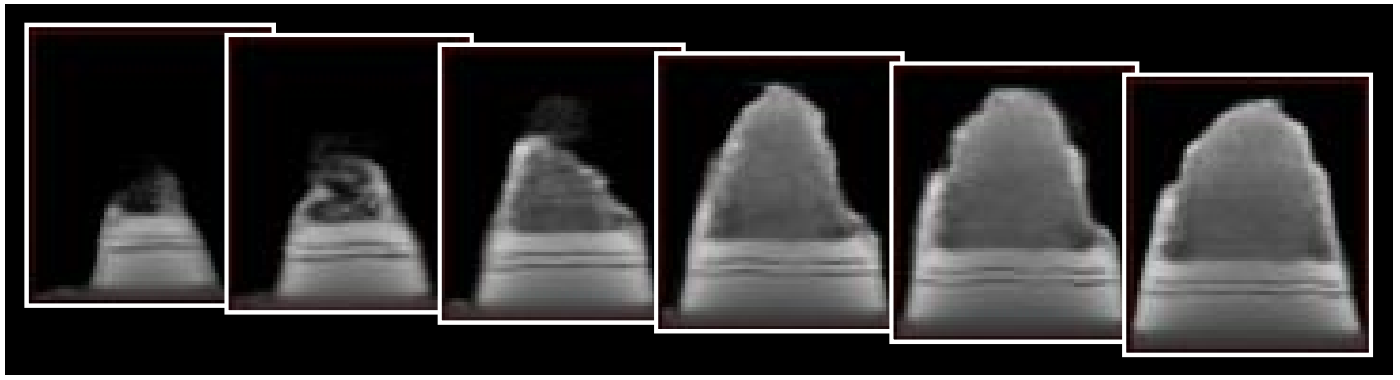
Top to bottom movie

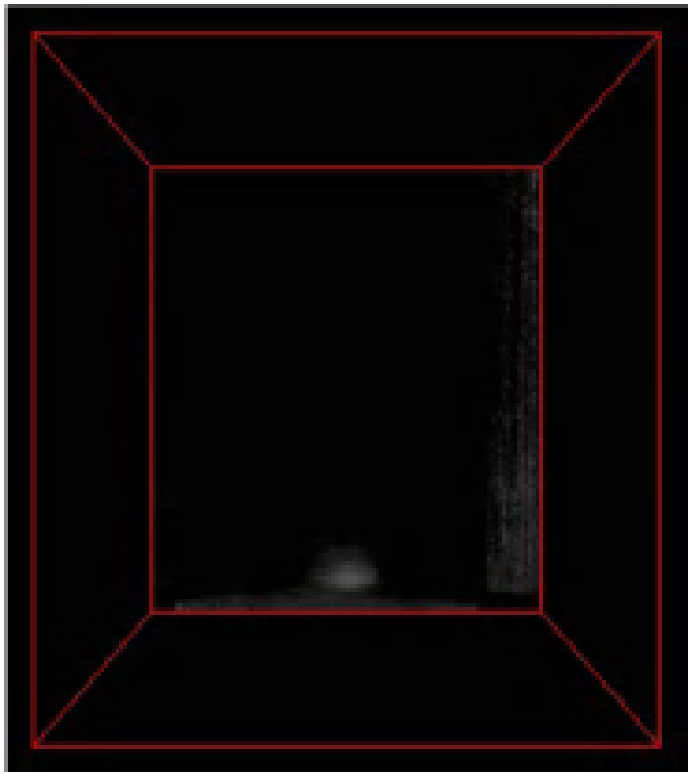


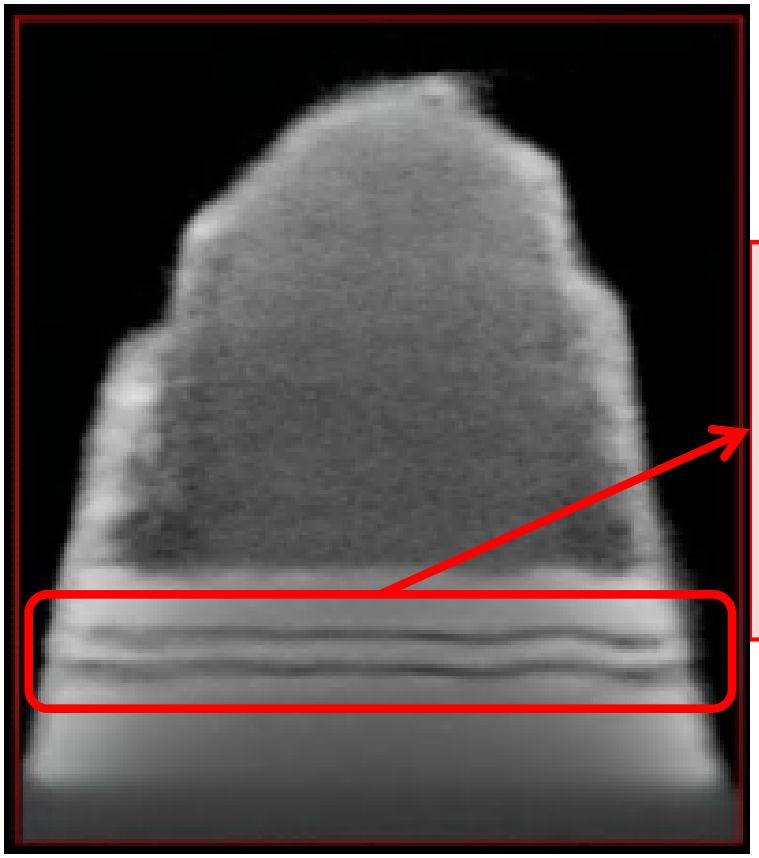
Useful for process evaluation of hard mask

Tomogram series : cross section



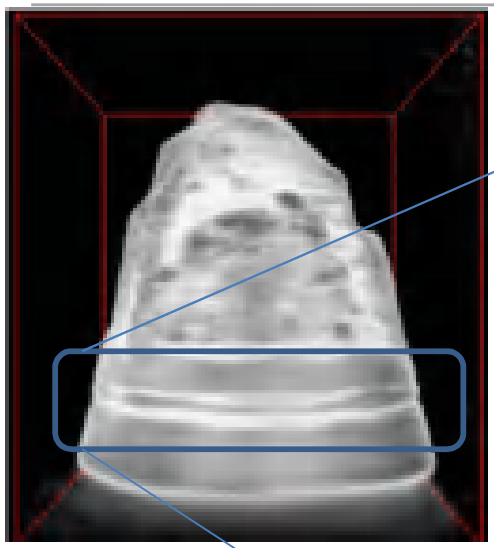


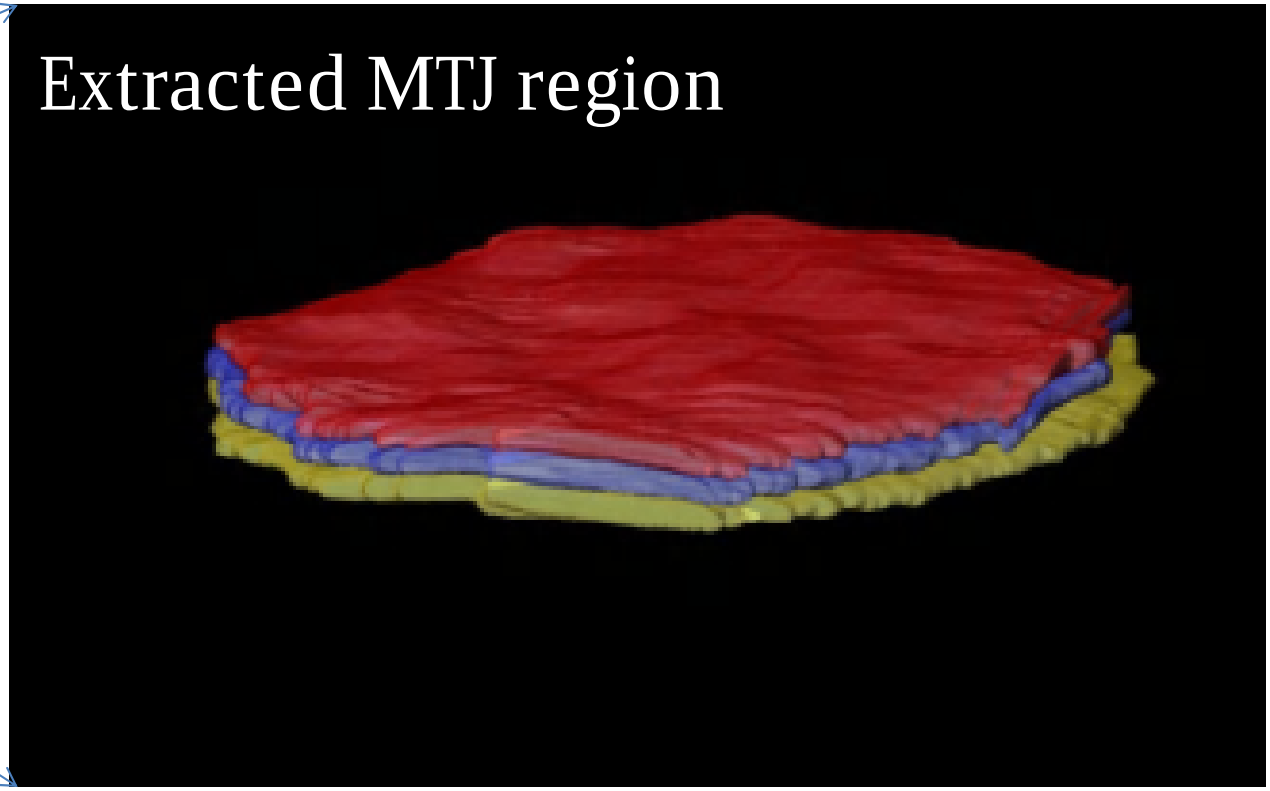




Evaluation of
CFB/MgO roughness and
thickness
from “ no-thickness ”
tomogram

Quantitative analysis : segmentation

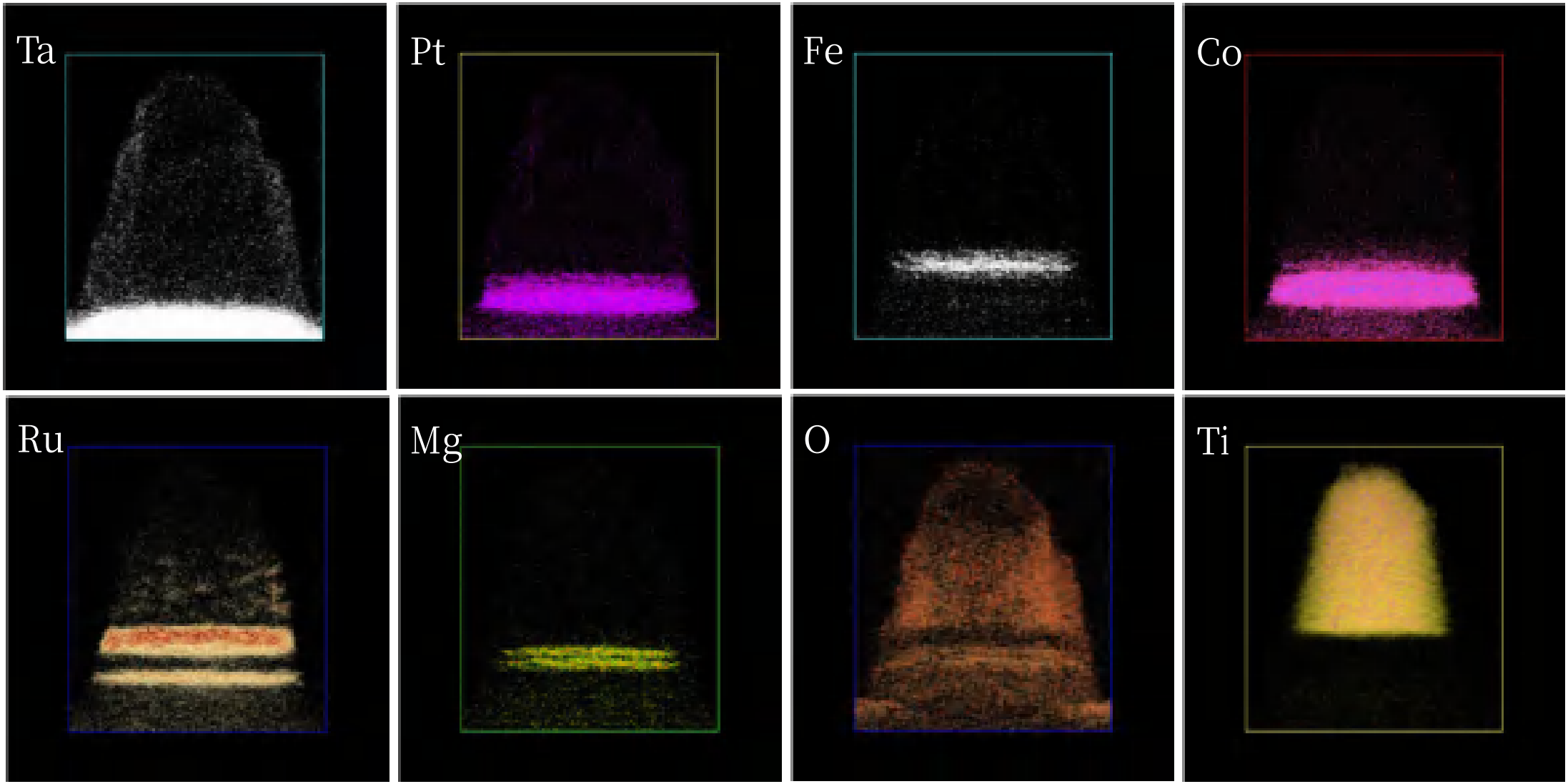




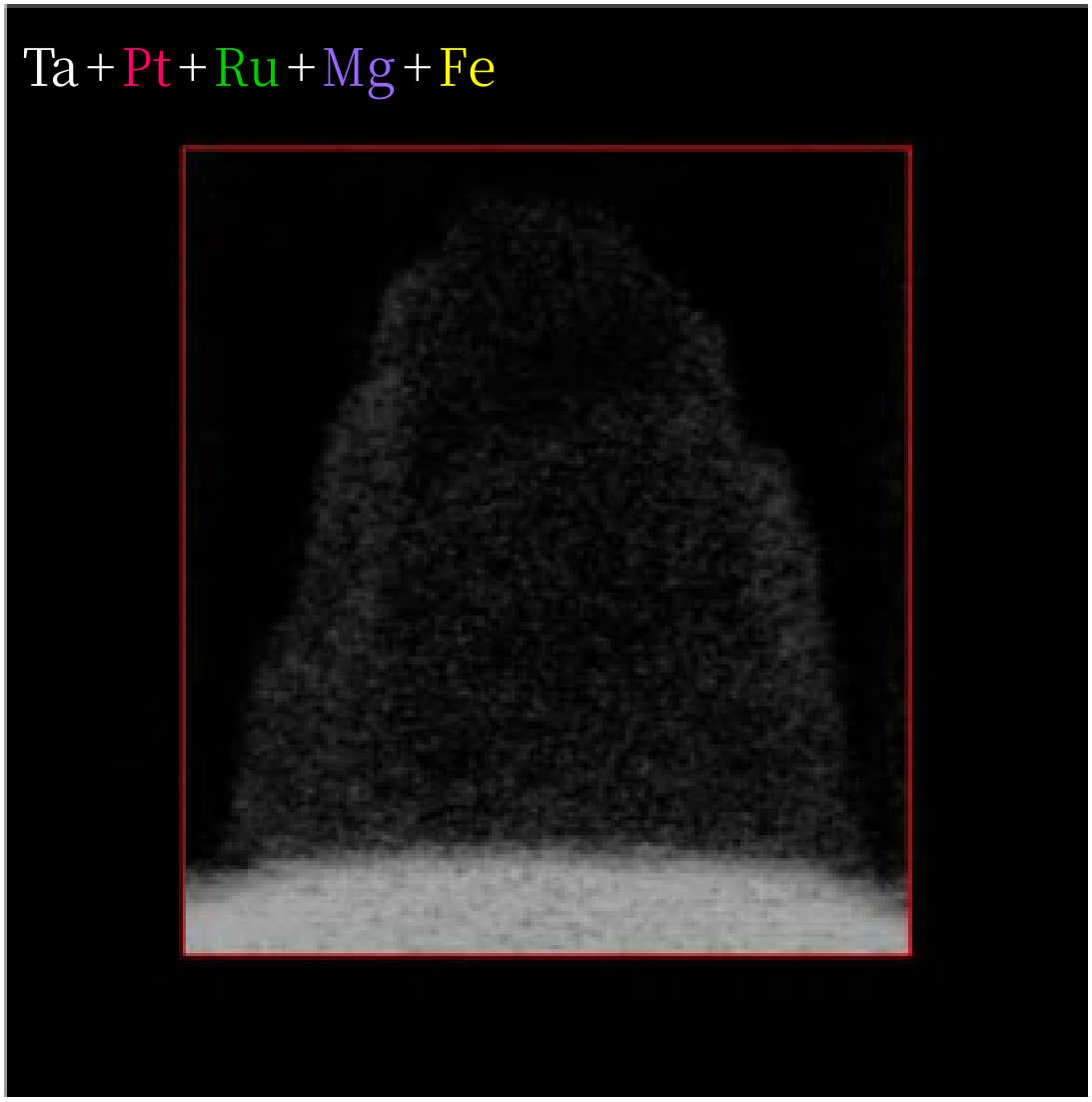
Extract “upper MgO / CFB / lower MgO” in 3D

The thickness / roughness information can be derived.

STEM EDX tomography results 1



STEM EDX tomography results 2



Good points

- EDX tomogram revealed 1nm-order thin lamination structure.
- deposits consist of Ru.

Bad points

- Roghness structure couldn't be recognized.
- Barrier edge detail structure couldn't be recognized.

Should be improved

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Conclusion

- 80nmϕ MTJ structure was investigated by 3D-TEM.
- “Rod-shape” FIB preparation made it possible to get higher resolution (<1nm) 3D tomogram.
  - ■ *HAADF-STEM tomogram revealed the thickness or roughness of barrier MgOs quantitatively, and this technique will be popular to evaluate MRAM process.*
  - ■ *EDX tomography gave us the information about deposits or damaged layer distribution roughly.*

Future subject

- Barrier edge structure analysis more precisely.
- 3D-EELS (higher resolution and chemical information)
- More information about spin or crystal structure