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Resolution of Non-Destructive Imaging for Buried Interfaces

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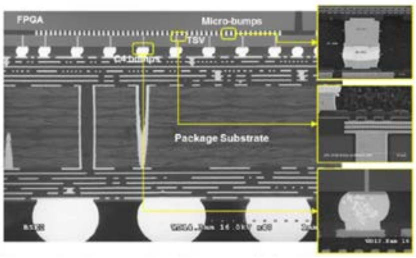
Cross-sectional image of MRAM

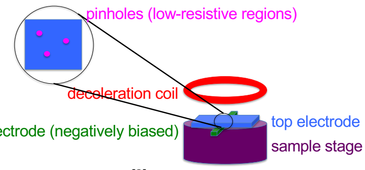
[1] https://www.everspin.com/



[2] http://electroiq.com/insights-from-leading-edge/2014/01/

- Cross-sectional sample fabrication induced strain.
- Non-destructive evaluation is required.
- Defects should be detected in nm resolution

Aims of this study



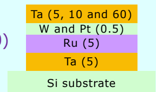
Imaging process for buried interfaces : [3]

1. Simulate electron flights in a multilayered structure at a series of decelerated electron-beam.
2. Select representative electron-beam for imaging.
3. Subtract and compare images taken at different electron-beam voltages to highlight any features appeared at each interface.

[3] A. Hirohata *et al.*, *Nat. Commun.* **7**, 12701 (2016).

Sample growth by sputtering (HiTUS)

- Ta (5) / Ru (5) / W (0.5) / Ta (5)
- Ta (5) / Ru (5) / W (0.5) / Ta (10)
- Ta (5) / Pt (0.5) / Ta (60)



Tungsten is the heavy metal.

Confirm the resolution of dispersed nano-particle by using non-destructive technique.

CASINO electron flight simulations [4]

- Landing position of an electron is calculated using

$$X_0 = \frac{d\sqrt{\log(R_1)}}{2\times 1.65}\times\cos(2\pi R_2)$$
$$Y_0 = \frac{d\sqrt{\log(R_1)}}{2\times 1.65}\times\cos(2\pi R_3)$$

($0 \leq R \leq 1$, random number)

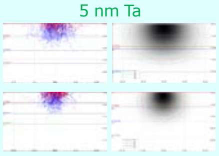
- For inelastic scattering, the separation between two successive collisions (S) with an electron-beam at E keV can be calculated as

$$E_{i+1} = E_i + \frac{dE}{dS}L$$
$$\frac{dE}{dS} = \frac{-7.85\times 10^{-3}\rho}{E_i}\times\sum_{j=1}^{n}\frac{C_j Z_j}{F_j}\ln\left(1.116\left(\frac{E_i}{J_j}+k_j\right)\right)\text{[keV/nm]}$$

(C, F, J, k and Z: material constants, ρ: density of a material and L: distance between elastic scattering)

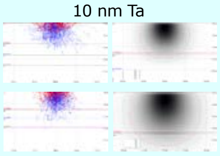
[4] D. Drouin *et al.*, *Scanning* **29**, 92 (2007).

5 nm Ta



- Electron beam reaches W at 0.9 keV.
- Electron beam reaches bottom of W at 1.1 keV.

10 nm Ta



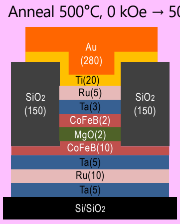
- Electron beam reaches W at 1.3 keV.
- Electron beam reaches bottom of W at 1.5 keV.

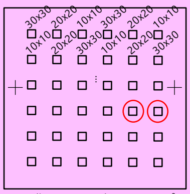
Magnetic tunnel junctions

Two distinctive junctions with high and low TMR ratios :

Ta, Ru	100 W, : DC	Ar 24.0 sccm (0.10 Pa), RT
CoFeB	100 W, : DC	Ar 24.0 sccm (0.10 Pa), RT
MgO	50 W, : RF	Ar 14.5 sccm (0.06 Pa), RT

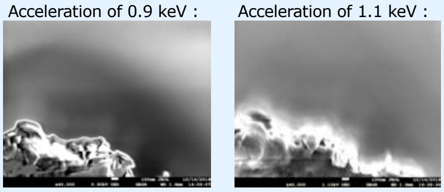
Anneal 500°C, 0 kOe → 500°C, 3 kOe





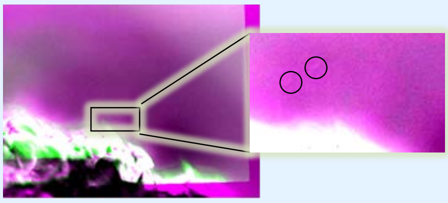
Non-destructive imaging through 5 nm Ta

Acceleration of 0.9 keV : / Acceleration of 1.1 keV :



* Scale : 100 nm, Magnification : 40,000

Subtraction between images taken at 1.0 and 1.2 keV :

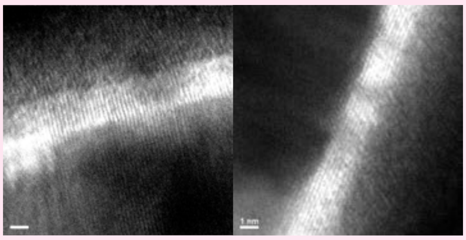


* Scale : 100 nm, Magnification : 40,000

- Maximum particle diameter : 110 nm
- Minimum particle diameter : < 10 nm
- Confirm some dispersed particles.
- Size distributions can be obtained.

Cross-sectional images

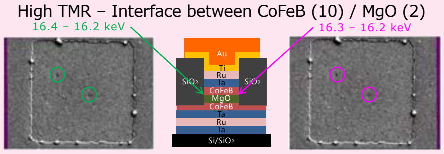
Two distinctive junctions with high and low TMR ratios :



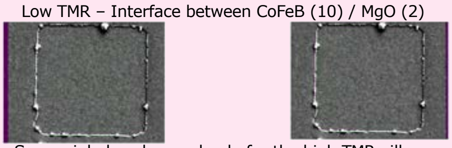
Junction with high TMR ratio / Junction with low TMR ratio

Non-destructive images at the top interfaces

High TMR – Interface between CoFeB (10) / MgO (2)



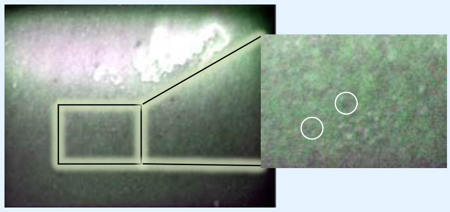
Low TMR – Interface between CoFeB (10) / MgO (2)



Some pinholes observed only for the high TMR pillars.

Non-destructive imaging through 10 nm Ta

Subtraction between images taken at 1.4 and 1.5 keV :

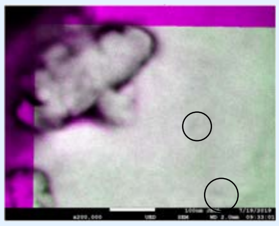


* Scale : 100 nm, Magnification : 70,000

- Maximum particle diameter : 67 nm
- Minimum particle diameter : 6.8 nm

Non-destructive imaging through 60 nm Ta

Subtraction between images taken at 4.7 and 5.0 keV :

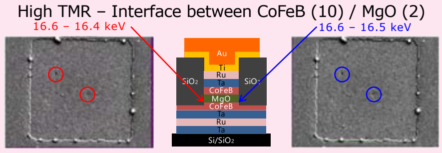


* Scale : 100 nm, Magnification : 200,000

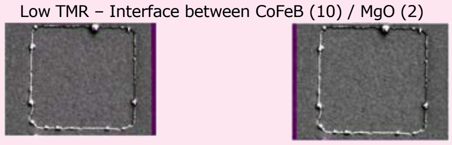
- Maximum particle diameter : 36 nm
- Minimum particle diameter : 11 nm

Non-destructive images at the bottom interfaces

High TMR – Interface between CoFeB (10) / MgO (2)



Low TMR – Interface between CoFeB (10) / MgO (2)



Some pinholes observed only for the high TMR pillars.

Summary

- We have successfully developed a new non-destructive method to image buried junctions.
- By controlling the electron-beam energy, we have demonstrated the contrast imaging of buried interfaces at a controlled depth.
- We can resolve particles in ~ 7 nm in size below 10 nm thick over layers.

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