Realization of high quality epitaxial current-perpendicular-to-plane giant magnetoresistive pseudo spin-valves on Si(001) wafer using NiAl buffer layer

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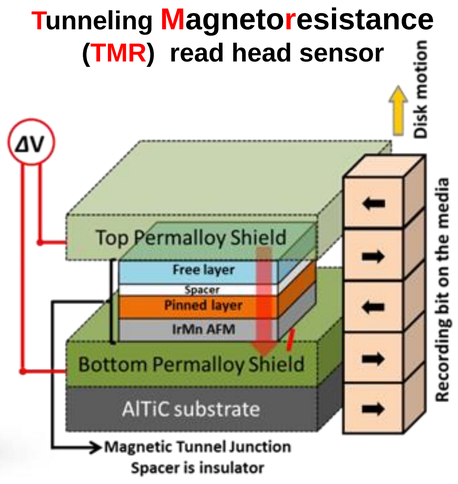
JSPS 独立行政法人 日本学術振興会 Japan Society for the Promotion of Science

革新的研究開発推進プログラム ImPACT Impulsing Paradigm Change through Disruptive Technologies Program

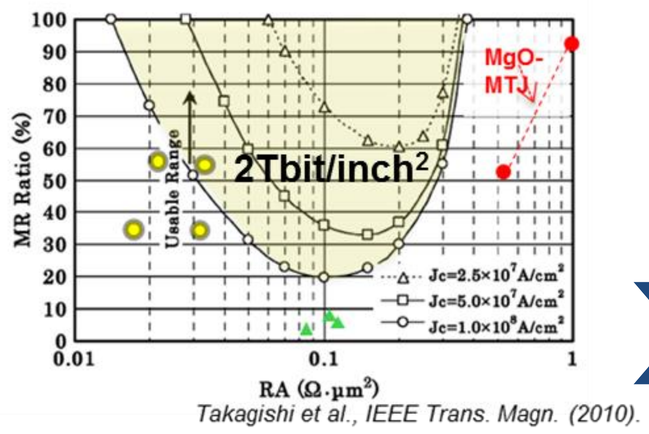
INTRODUCTION

CPP-GMR read head sensors for Hard disk drives (HDDs)

Tunneling Magnetoresistance (TMR) read head sensor



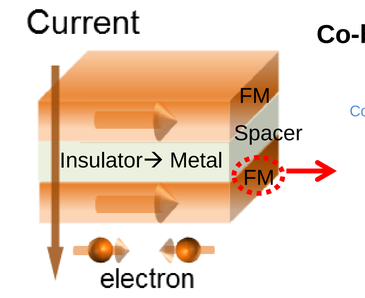
Hard disk drive (HDD) with larger and larger capacity is in strong need!



Takagishi et al., IEEE Trans. Magn. (2010).

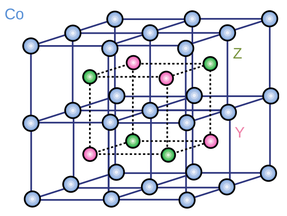
Problem:

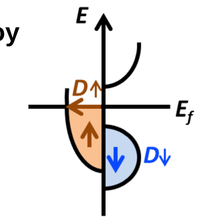
- **Currently commercial TMR read head sensor hit its limit for areal density of >2 Tbit/inch²!!!**
  → Significant drop of MR ration with reducing RA



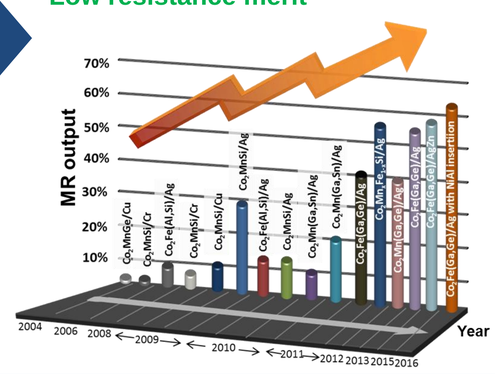
Low resistance merit

Co-based Full Heusler alloy Co_2YZ





Spin-polarization P=100%



1.Caballero et al, J. MMM **198-199**,55 (1999)
2. Hoshiya et al, JAP **56**, 6774 (2004)
3. Yakushiji et al, APL **88**, 222504 (2006)
4. Furubayashi et al, APL **93**, 122507 (2008)
5. Sakuraba et al, APL **94**, 012511 (2009)
6. Kodama et al, JAP **105**, 07E905 (2009)
7. Iwase et al, APEX **2**, 063003 (2009)
8. Furubayshi et al, APL **93**, 122507 (2008)
9. Hase et al, JAP **108**, 093916 (2010)
10. Hase et al, JAP **109**, 07E112 (2011)
11. Takahashi et al, APL **98**, 152501 (2011)
12. Sakuraba et al, APL **101**, 252408 (2012)
13. Takahashi et al, JAP **113**, 223901 (2013)
14. Li et al, APL **103**, 042405 (2013)
15. Du et al, APL **107**, 112405 (2015)
16. Jung et al, APL **108**, 102408 (2016)

MOTIVATION

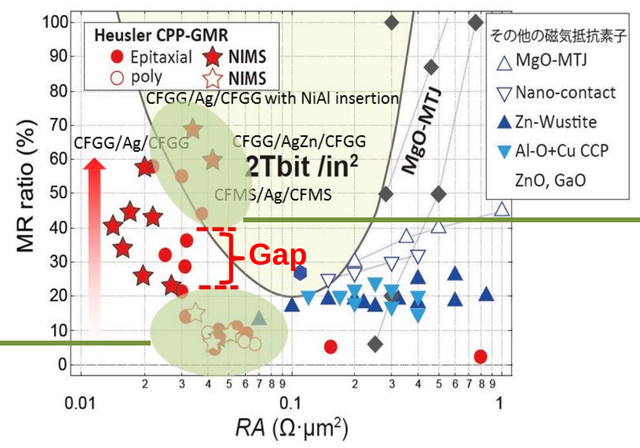
Poly-CPPGMR

CPP-GMR device

Si/SiO_2-subs.

- Poor MR output
- Polycrystalline
- Practical
- Low cost

Si/SiO_2 substrate
2 inch Diameter
Cost: ~5,000 yen



Takagishi et al, IEEE Trans. Magn. 46, 2086 (2010)

Epi-CPPGMR

CPP-GMR device

MgO(001)-subs.

- High MR output
- Single crystalline
- Unpractical
- High cost

MgO substrate
2 inch Diameter
Cost: ~50,000 yen

CPP-GMR device

Si(001)-subs.

Si(001)-based Epi-CPPGMR

EXPERIMENT

• Device structure

CPP-GMR device

X buffer material

Si(001)-subs.

CPP-GMR structure →

Ru (8 nm)
Ag (5 nm)
CFGG (10 nm)
Ag (5 nm)
CFGG (10 nm)
Ag (50 nm)
NiAl (50 nm)
Si(001)-subs.

CFGG=$Co_2Fe(Ga_{0.5}Ge_{0.5})$

• Buffer material selection

We choose "NiAl" !!!

Merit:

1. High thermal stability with a melting point up to 1620°C.
2. Almost perfect lattice matching (<1%) with Co-based Heusler alloy.
3. Relatively small lattice mismatch (~6%) with Si substrate.

• Measurement methods

- Crystal structure and epitaxial growth analysis → XRD and RHEED
- Surface morphology → AFM
- Magnetro-resistance transportation property → direct current four-probe method
- Microstructure analysis→ TEM

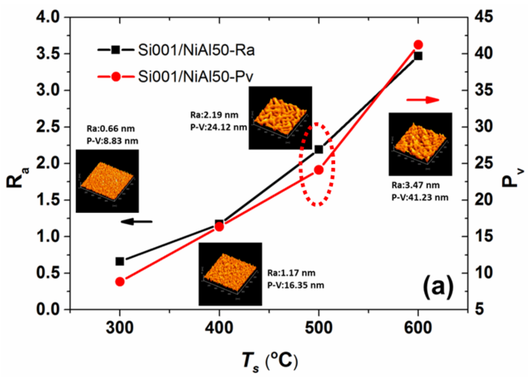
RESULTS AND CONCLUSION

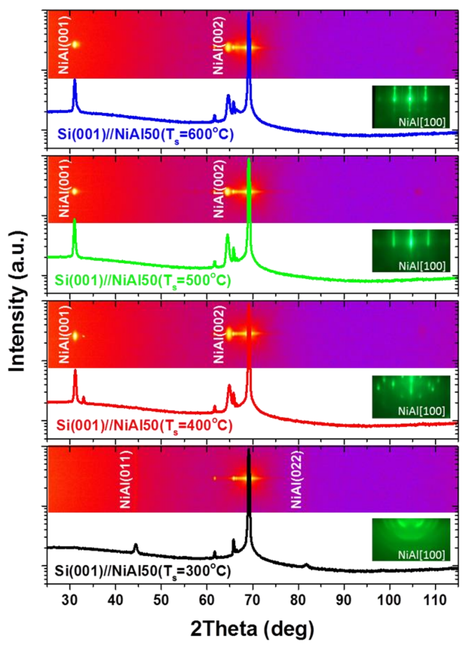
1. NiAl single layer on Si(001)

NiAl (50nm)

Si(001)-subs.

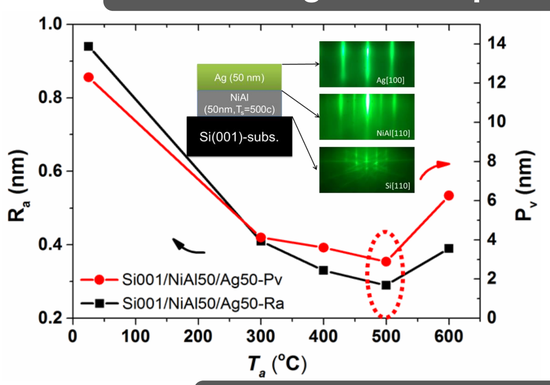
Si(001)-subs./$Ni_{50}Al_{50}$ (50nm)
Deposition temperature T_s=300, 400, 500, 600°C

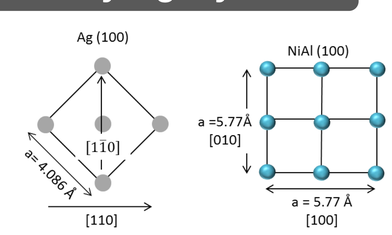




- Epitaxial growth start to occur at the deposition temperature of 400°C.
- Fully epitaxial growth can be obtained at deposition temperature higher than 500°C.
- Surface roughness increase with increasing deposition temperature.

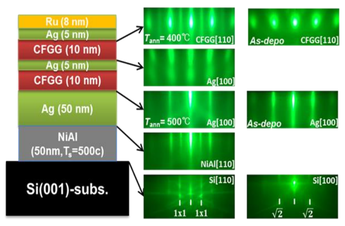
2. Roughness improvement by Ag layer

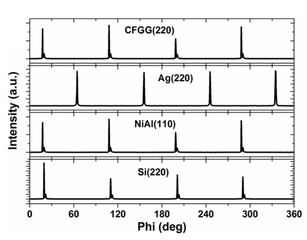




- Deposition of Ag layer and Post annealing process can improve layer surface roughness.

3. Epitaxial relationship of each layer

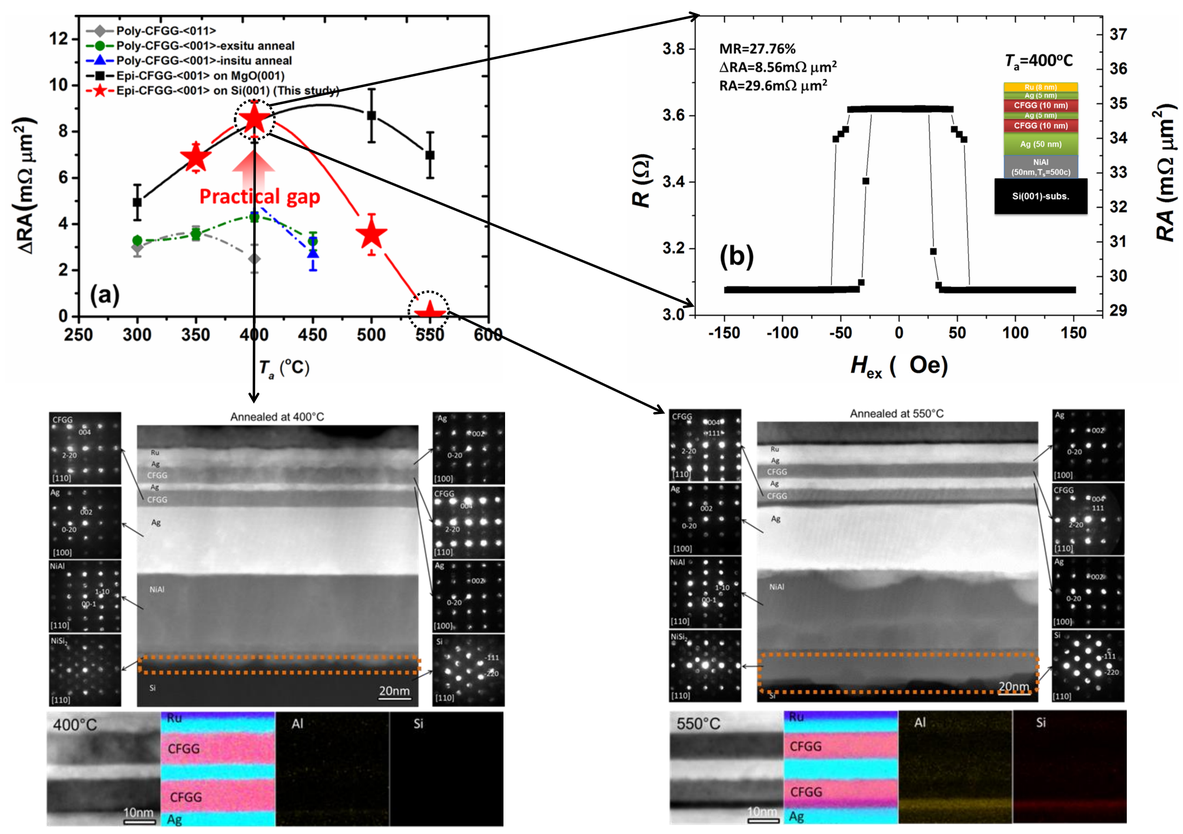




Fully Epitaxial On Si sub.!

Epitaxial relationship:
Si(001)[110]//NiAl(001)[110]//Ag(001)[100]//CFGG(001)[110]

4. Magneto-transport property and Microstructure analysis



- CPP-GMR devices on a Si(001) substrate presents comparable MR outputs with those grown on an MgO(001) substrate.
- Expansive impractical MgO substrate can be replaced with the Si substrate to achieve high performance devices for practical applications!!!
- Interdiffusion is the reason why MR drop seriously at high annealing temperature.

5. Conclusion

1. By depositing NiAl on Si at an elevated temperature of 500°C, a smooth and epitaxial *B2*-type NiAl(001) layer can be obtained.
2. Fully epitaxial CPP-GMR device on Si wafer was realized by using NiAl buffer layer for the first time.
3. CPP-GMR devices on a Si(001) substrate presents comparable MR outputs with those grown on an MgO(001) substrate.

Which is a great breakthrough for practical application!

Can be extended to various spintronic application (like MTJs in MRAM…)!

For more detail, please see the following reference: **J. Chen *et al.*, APL Mater. 4, 056104 (2016).**