Spin transfer torque in magnetic tunnel junctions with wedge MgO barrier

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Introduction

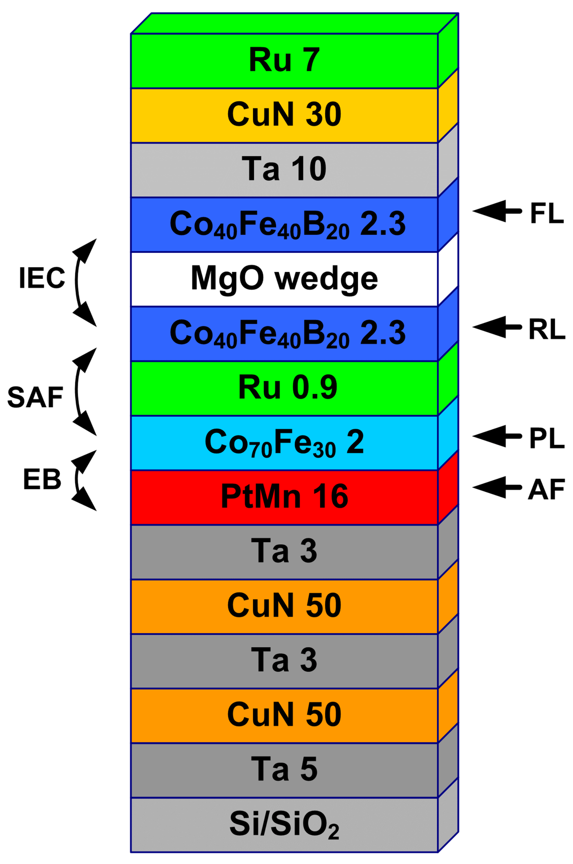
High density and fast MRAM can be implemented using the **spin transfer torque** (**STT**) effect, i.e., free layer magnetization reversal induced by a flow of a high density spin-polarized current through a MTJ. STT was introduced theoretically by Slonczewski and Berger [1] and experimentally demonstrated in spin valve GMR and TMR multilayer structures.

Aim

Crucial issues of STT in MTJs are a reduction of the **critical current density**, which is necessary for switching the junction and a reduction of the resistance area (RA) product. Here, we discuss the influence of MgO barrier thickness on the **interlayer exchange coupling** (**IEC**) energy and **STT** effect in MTJs with a MgO wedge barrier.

Sample preparation

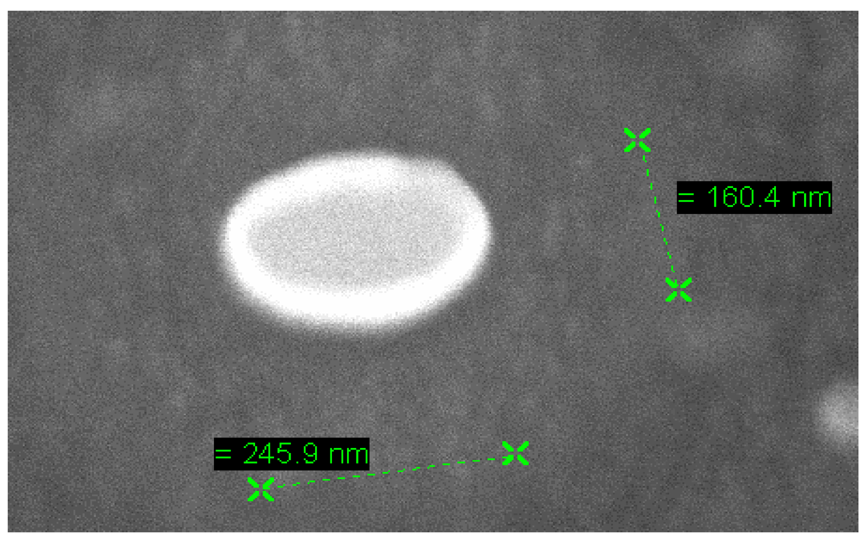
A1. Deposition



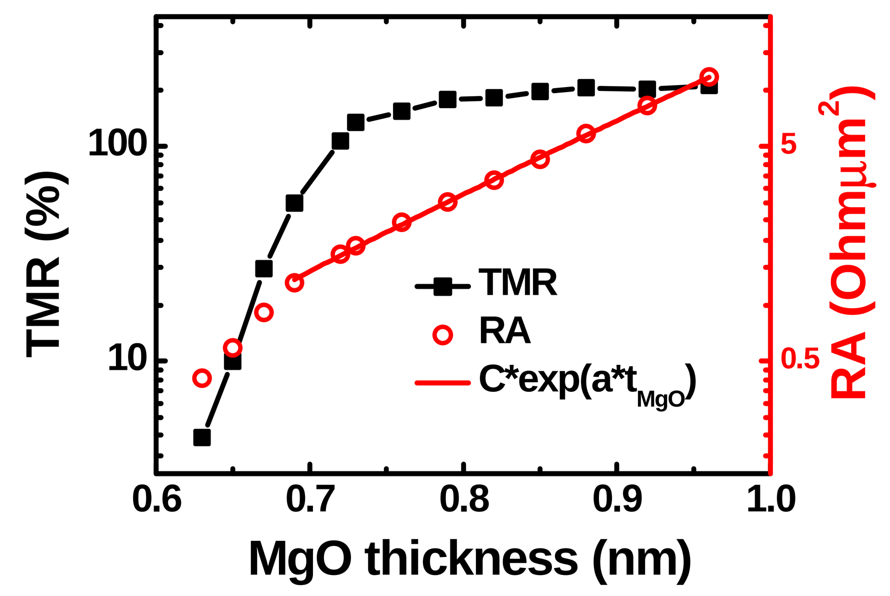
- deposited using a Timaris PVD cluster tool system from **Singulus Technologies**
- DC and RF magnetron sputtering
- linear dynamic deposition (LDD) wedge technology
- the MgO barrier thickness between 0.62 and 0.96 nm along 8 inch wafer (slope rate of 0.017 nm/cm)
- base pressure before deposition was 10^{-9} mTorr
- annealed in a high-vacuum furnace for 2h at 360C under an applied magnetic field of 10kOe

A2. E-beam lithography

- 2 step lithography process using e-beam lithography, ion milling, lift-off
- 3 sizes:
  - 0.03 (160 x 250 nm)
  - 0.08 (280 x 430 um)
  - 0.13 um² (280 x 620 nm)



A3. Wafer level characterization

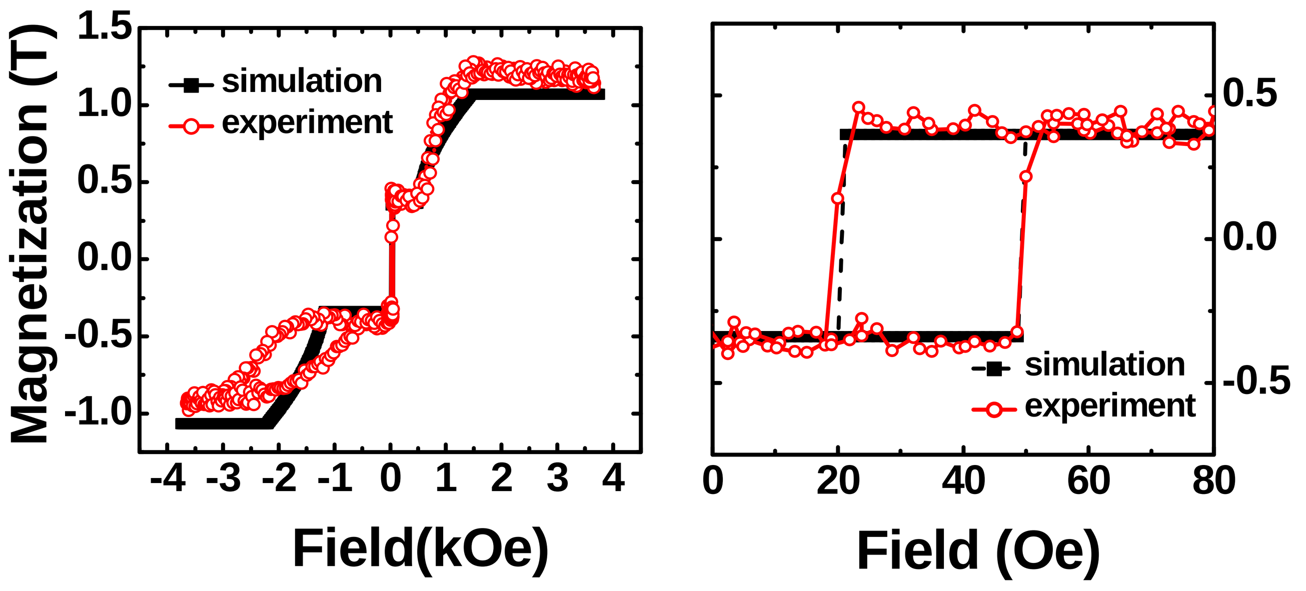


- for thick MgO barriers (down to 0.75 nm) the change of the **TMR** value is relatively small (from **170%** to **150%**)
- when the RA < 2 Ohmum² (0.7 nm MgO) the **TMR** starts to drop (the barrier imperfection)

Interlayer exchange coupling

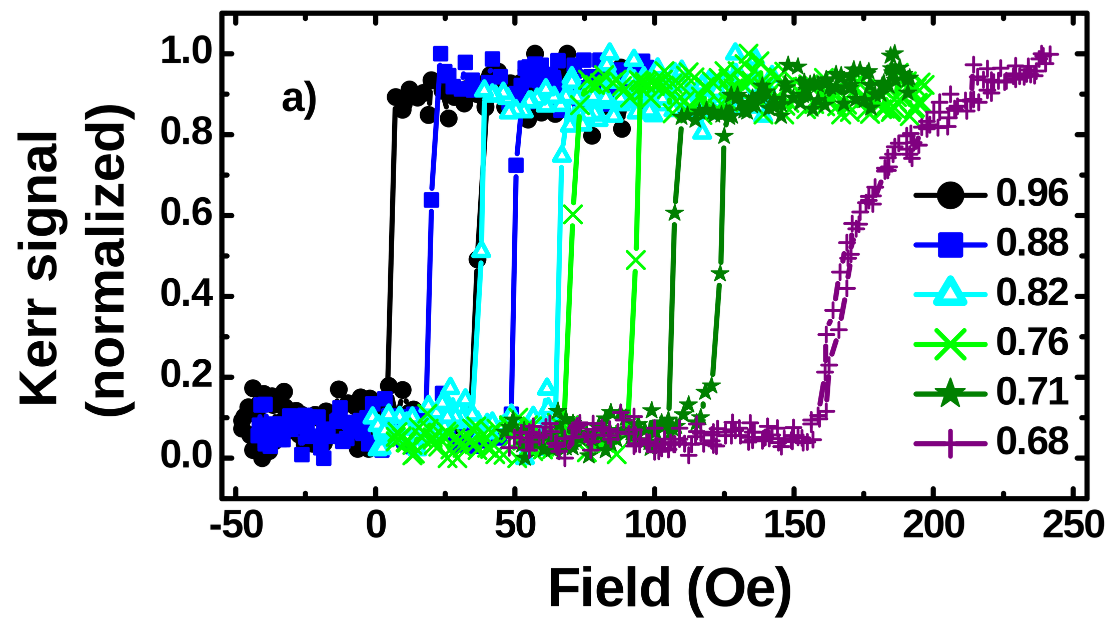
B1. Energy model [2]

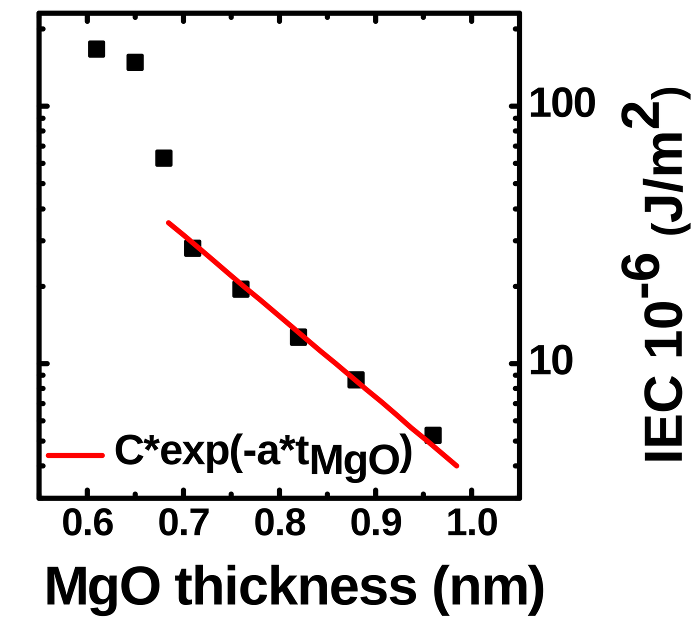
$$E = -t_{FL}\mu_0 M_{FL} H\cos\theta_{FL} - K_{FL}t_{FL}\cos^2\theta_{FL} - J_{IEC}\cos(\theta_{FL}-\theta_{RL}) - t_{RL}\mu_0 M_{RL} H\cos\theta_{RL} - K_{RL}t_{RL}\cos^2\theta_{RL} - J_{SAF}\cos(\theta_{FL}-\theta_{RL}) - t_{PL}\mu_0 M_{PL} H\cos\theta_{PL} - K_{PL}t_{PL}\cos^2\theta_{PL} - J_{EB}\cos(\theta_{FL}-\theta_{RL}) - K_{AF}t_{AF}\cos^2\theta_{AF}$$



- $\mu_0 M_{CoFeB} = \mu_0 M_{FL} = \mu_0 M_{RL} =$ **1.35** T,
- $\mu_0 M_{CoFe} = \mu_0 M_{PL} =$ **1.6** T,
- $K_{FL} = K_{RL} =$ **940** J/m³
- $K_{PL} =$ **100** J/m³
- $K_{AF} =$ **60** kJ/m³
- $J_{SAF} =$ **−0.221** mJ/m²
- $J_{EB} =$ **0.188** mJ/m²

B2. IEC

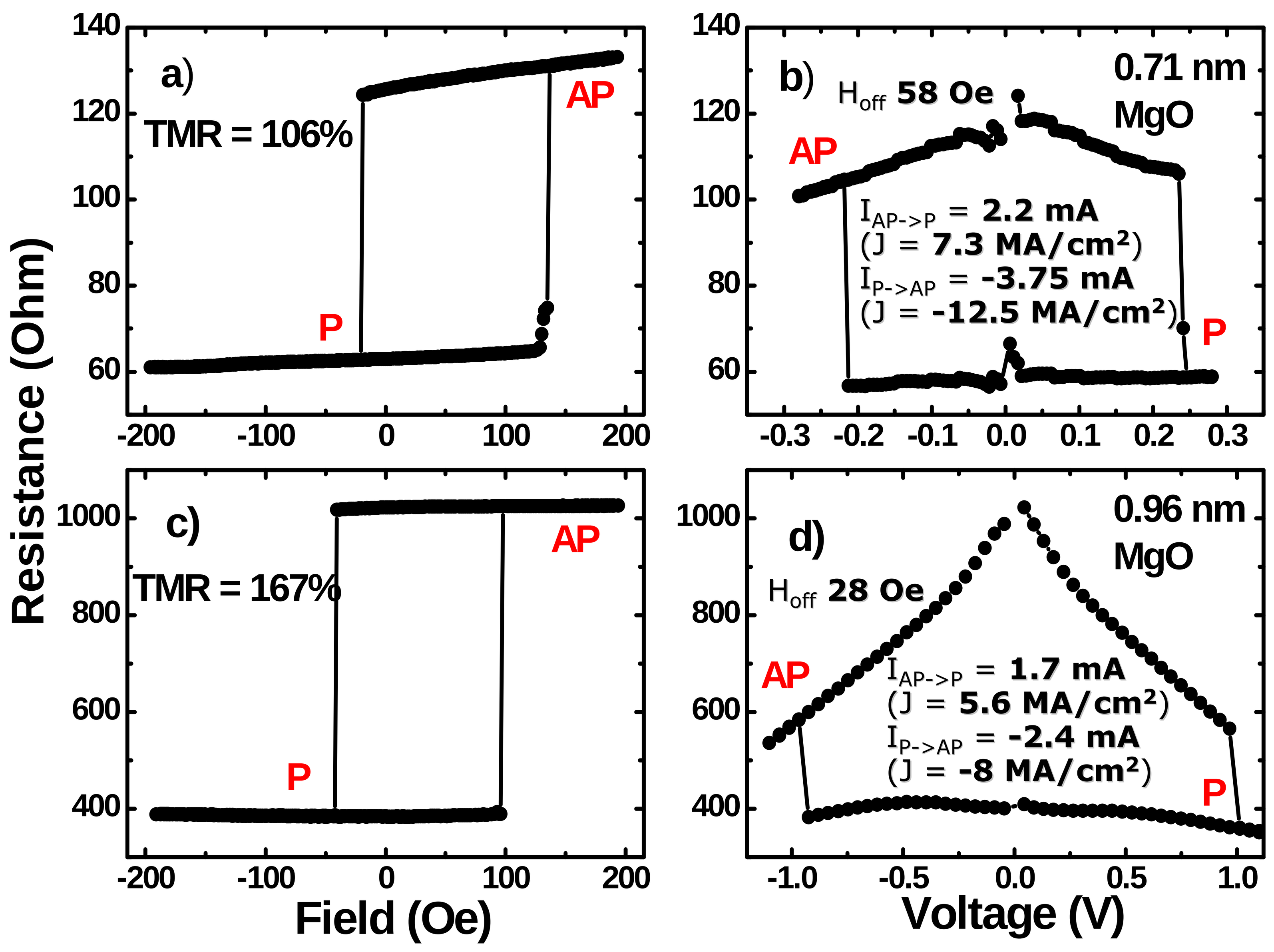


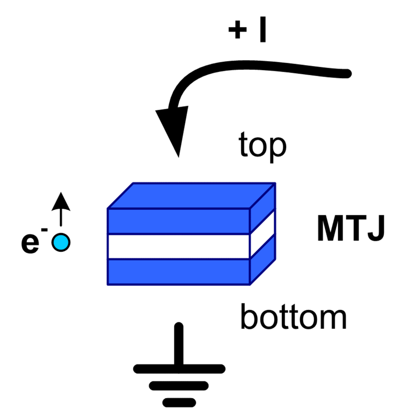


- **ferromagnetic IEC** between the FL and RL
- Katayama [3] on epitaxial Fe(001)/ wedge MgO(001)/ Fe(001) observed transition from a ferromagnetic to antiferromagnetic coupling below 0.8 nm

Current induced magnetization switching

C1. CIMS experiment



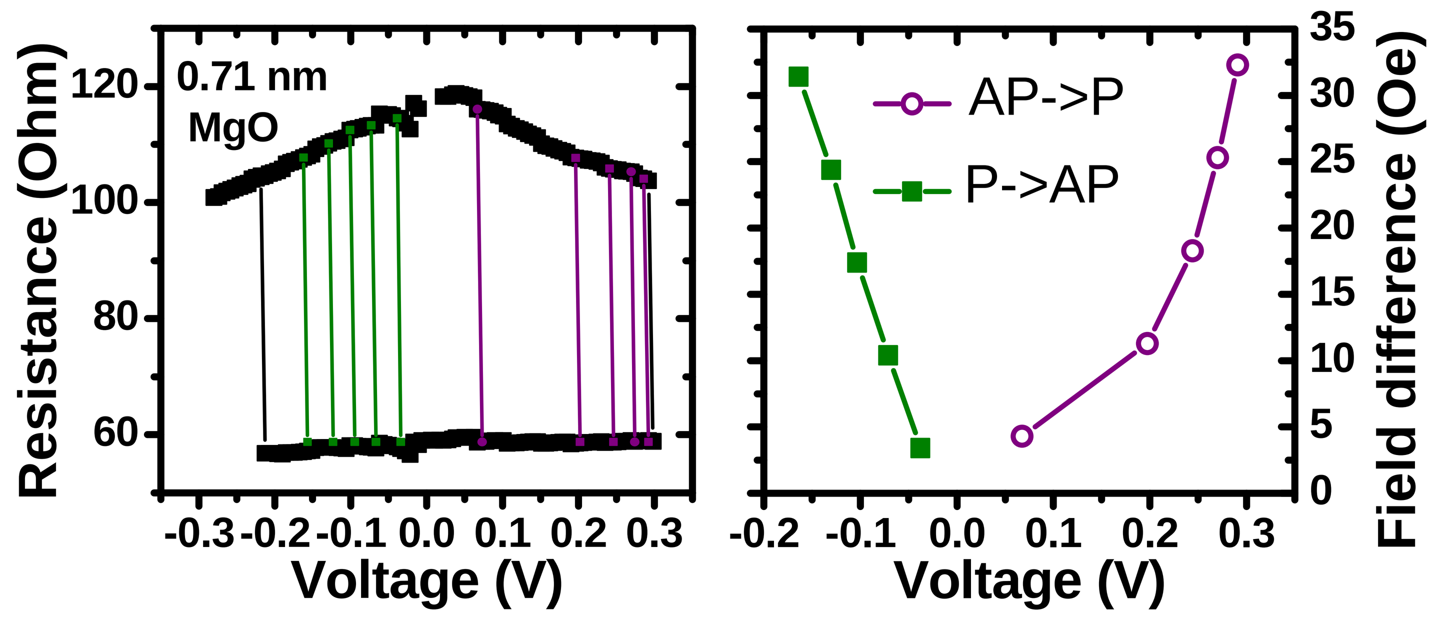


C2. Conclusions

- higher switching current density was observed for the MTJ with 0.71 nm MgO
- the decrease of the critical current density with increasing barrier thickness can qualitatively be explained by an increase of tunneling spin polarization (**TSP**)
- more efficient spin filter effect in the thicker MgO barrier [5]
- TSP derived from the TMR ratio is **0.67** for the MTJ with 0.96 nm MgO and **0.58** for the MTJ with 0.71 nm MgO

C3. Outlook

- the model of the critical current density presented in [4] does not explain quantitatively the values of the switching current observed in the experiment



[1] - Slonczewski J 1996 *J. Magn. Magn. Mater.* **159** 1 , Berger L 1996 *Phys.Rev.* B **54** 9353

[2] - Czapkiewicz M, Zoladz M, Wrona J, Wisniowski P, Rak R, Stobiecki T, Kim C G, Kim C O, Takahashi M and Tsunoda M 2004 *Phys. Staus Solidi* **241** 7

[3] - Katayama T, Yuasa S, Velev J, Zhuravlev M Ye, Jaswal S S and Tsymbal E Y 2006 *Appl. Phys. Lett.* **89** 112503

[4] - Huai Y, Pakala M, Diao Z, Apalkov D, Ding Y and Panchula A 2006 *J. Magn. Magn. Mater.* **304** 88

[5] - Itoh H 2007 *J. Phys. D: Appl. Phys.* **40** 1228

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