Antiferromagnetic coupling in CoFeB/Ru/CoFeB prepared by sputtering and ion beam deposition

A.Zaleski [1], M. Czapkiewicz[1], J. Kanak[1], P. Wiśniowski[1,2], T. Stobiecki[1], S. Cardoso[2], P. P. Freitas[2]

[1] Department of Electronics, AGH University of Science and Technology, Al. Mickiewicza 30, 30-059 Kraków, Poland

[2] INESC Microsystems and Nanotechnologies, Rua Alves Redol, 9-1, 1000-029 Lisbon, Portugal

Motivation

MgO-based magnetic tunnel junctions (MTJs) exhibit high tunnel magnetoresistance (TMR) ratios and low R×A product together with current-induced magnetization switching (CIMS). Free layer, represented by CoFeB/Ru/CoFeB synthetic antiferromagnets (SAFs) consisting of two or more ferromagnetic layers separated by a non-magnetic spacer (Ru) is proposed to reduce the switching current (field) and to decrease the stray field.

Aim

Our aim is to find the optimal Ru spacer thickness (t_{Ru}), deposition technique and post-deposition thermal treatment in order to obtain SAFs with high antiferromagnetic (AF) coupling energy, low stray field and high magnetic volume in order to withstand thermal fluctuations. This will lead to reduction of critical current density in CIMS while maintaining a high thermal stability factor that is important for magnetic random access memories applications.

Experimental procedure

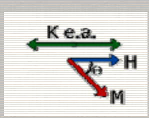
SAFs CoFeB/Ru/CoFeB with varied t_{Ru} were prepared by magnetron sputtering with t_{Ru} in the range of 5 to 8 Å and ion–beam deposition (IBD) with t_{Ru} in the range of 5 to 9 Å and 5 to 12 Å for multilayers (MLs). Both series of samples were annealed at 280 °C in vacuum, 800 kA/m field.

Samples magnetization hysteresis loops were measured by means of VSM and MOKE magnetometry.

The TMR loops of the MTJs were measured at room temperature using a four-probe method with dc bias and magnetic field of up to 140 Oe.

Calculation of interlayer exchange coupling energy

$$E = -J_1\cos(\theta_1-\theta_2) - J_2\cos^2(\theta_1-\theta_2)$$
$$- K_{FM1}t_{FM1}\cos^2\theta_1 - K_{FM2}t_{FM2}\cos^2\theta_2$$
$$- t_{FM1}\mu_0 M_{FM1} H\cos\theta_1 - t_{FM2}\mu_0 M_{FM2} H\cos\theta_2$$



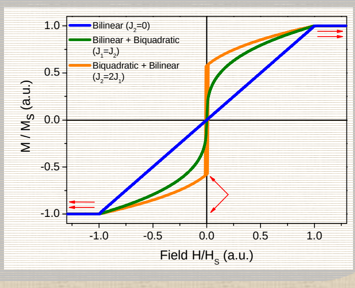
E – Energy per area [J/m^2],

J_1 – bilinear coupling energy (preferred parallel, J_1 >0 or antiparallel, J_1 <0 orientation),

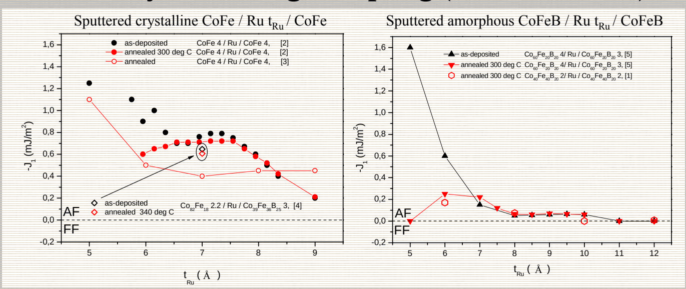
J_2 – biquadratic coupling energy (J_2 <0 : preferred 90° orientation),

K_{FM1}, K_{FM} – anisotropy constants of top and bottom layers respectively.

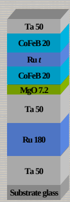
Calculated M(H) loops for different ratios of bilinear and biquadratic coupling terms, K_{FM}=0



Interlayer exchange coupling (literature data)



Sputtered SAFs



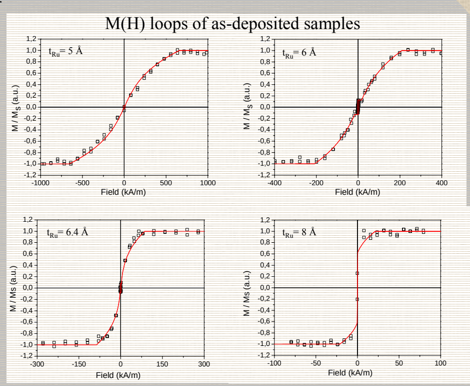
t_{Ru}= 5, 6, 6.4, 8 Å

$Co_{39}Fe_{36}B_{25}$

$K_{FM1}=K_{FM2} \leq 50$ J/m^3

$K_{FM}t_{FM} = 1\times10^{-4}$ mJ/m^2 <<J_1

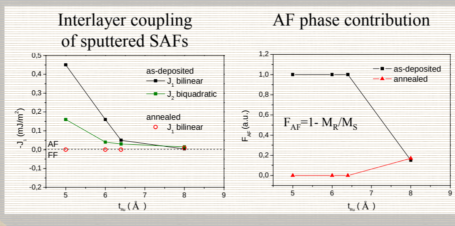
M(H) loops of as-deposited samples



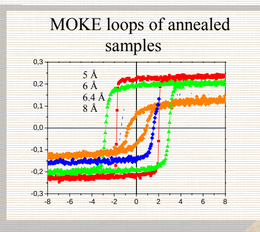
Parameters used for M(H) calculation

t Ru [A]	M_{FM1} [T]	M_{FM2} [T]	J_1 [mJ/m^2]	J_2 [mJ/m^2]
5.0	0.9	0.95	-0.450	-0.160
6.0	0.85	1.1	-0.160	-0.040
6.4	0.85	1.0	-0.050	-0.030
8.0	0.80	1.0	-0.004	-0.015

Interlayer coupling of sputtered SAFs / AF phase contribution



MOKE loops of annealed samples

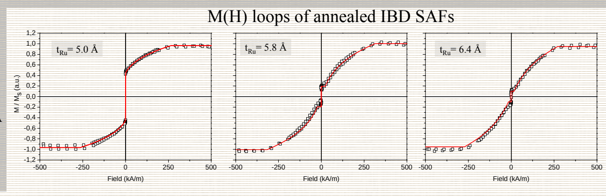


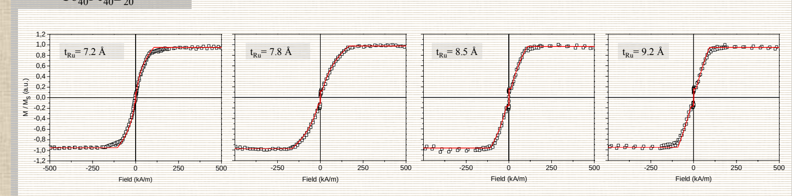
Ion Beam Deposited SAFs

t_{Ru}= 5, 5.8, 6.4, 7.2, 7.8, 8.5 and 9.2 Å

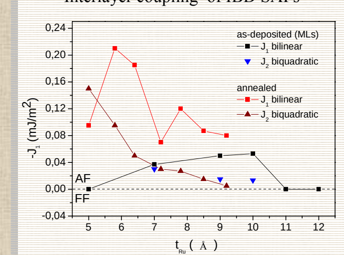
$Co_{40}Fe_{40}B_{20}$

M(H) loops of annealed IBD SAFs





Interlayer coupling of IBD SAFs

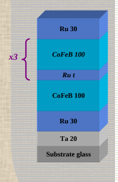


Parameters used for M(H) calculation

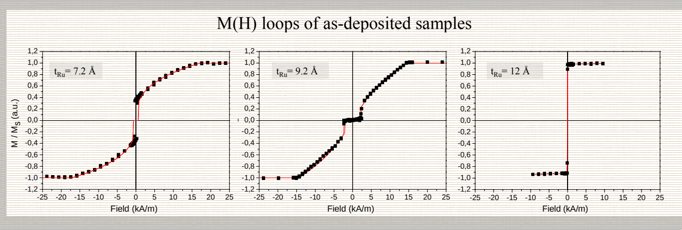
t Ru [A]	M_{FM1} [T]	M_{FM2} [T]	J_1 [mJ/m^2]	J_2 [mJ/m^2]
5.0	0.78	1.15	-0.095	-0.150
5.8	0.85	1.18	-0.210	-0.095
6.4	0.80	1.07	-0.185	-0.050
7.2	0.85	1.05	-0.070	-0.030
7.8	0.85	1.10	-0.120	-0.027
8.5	0.8	1.13	-0.087	-0.015
9.2	0.79	1.13	-0.080	-0.005

$K_{FM1}=K_{FM2} \leq 50$ J/m^3 · $K_{FM}t_{FM} = 1\times10^{-4}$ mJ/m^2 , $K_{FM}t_{FM}$ <<J_1

Ion Beam Deposited SAFs (MLs)



M(H) loops of as-deposited samples



References

[1] J. Hayakawa et al. JJAP Vol. 45, No. 40, 2006, p. L1057

[2] W.Maas et al. (Singulus), data available at http://layer.uci.agh.edu.pl/A.Zaleski/Data/SOMMA.pdf

[3] Z. Lu et al. JAP Vol. 91, (200) 7116

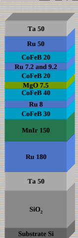
[4] A. Zaleski et al. (to be published), data available at http://layer.uci.agh.edu.pl/A.Zaleski/Data/PM_AGH.pdf

[5] N. Wiese et al. APL Vol. 85, (2004), 2020

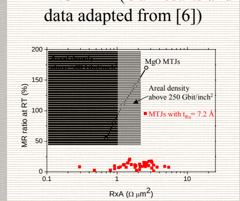
[6] S.Yuasa et al.. J. Phys. D.: Appl. Phys. No 40, (2007), R337

[7] F. Stobiecki et al. J. Non-crystalline Solids No.88, (1986), 209

TMR measurements



TMR vs R ×A (Our results and data adapted from [6])



Size of the MTJs varied from 70 nm x 100 nm to 400 nm x 900 nm

Conclusions

- In the case of sputtered SAFs annealing leads to strong deterioration of AF coupling particularly for thin Ru spacer due to thermally-activated diffusion of boron atoms and crystallization of CoFeB layer [7].
- In the case of SAFs obtained by IBD maximum of bilinear exchange coupling is observed at t_{Ru}= 5.8 Å. Biquadratic exchange coupling decreases with Ru thickness increase.
- Patterned MTJs (nanopillars, sizes down to 70 nm × 100 nm) with SAF as a free layer and MgO barrier show low TMR values (up to 22 %) and low R×A product (less than 10 Ωμm^2). Introductory characterization showed that the samples had poor uniformity. Better control of deposition and nanofabrication processes is of crucial importance for improving the quality of MTJs.

Acknowledgement: This work was supported by the EU MRTN-CT-2006-035327 SPINSWITCH