Experimental report

05/09/2022

Proposal: **5-54-336** **Council:** 4/2020

Title: Effect of interlay interdiffusion and antiferromagnetic grain aligmenton the pinning strength in IrMn/(Co,CoFe) bilayers and multilayers

Research area: Physics

This proposal is a continuation of 5-54-285

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Samples: {Ta 15A Ru 20A / IrMn3 40A / Co 30A}10 / Ru 20A annealed at 250C

5) Ta 15A Ru 20A / IrMn3 40A / Co 30A / Ru 20A not annealed
2) {Ta 15A Ru 20A / IrMn3 40A / Co 30A}10 / Ru 20A annealed at 300C
3) {Ta 15A Ru 20A / IrMn3 40A / Co70Fe30 30A}10 / Ru 20A annealed at 250C
4) {Ta 15A Ru 20A / IrMn3 40A / Co70Fe30 30A}10 / Ru 20A annealed at 300C
6) Ta 15A Ru 20A / IrMn3 40A / Co 30A / Ru 20A annealed at 300C
7) Ta 15A Ru 20A / IrMn3 40A / Co70Fe30 30A / Ru 20A not annealed
8) Ta 15A Ru 20A / IrMn3 40A / Co70Fe30 30A / Ru20A annealed at 300C

Instrument	Requested days	Allocated days	From	To
SUPERADAM	8	6	14/09/2021	20/09/2021

Abstract:

Ferromagnetic (FM) / antiferromagnetic (AFM) bilayers are widely used in magnetic recording read heads and in magnetic random access memory (MRAM) for pinning of reference layers or synthetic antiferromagnets in magnetic tunnel junctions (MTJs). Processing such devices involves numerous annealing steps at different temperatures, which may lead to interdiffusion at the FM/AFM interface and thus to degradation of interfacial exchange coupling strength. Pinning strength in polycrystalline FM/AFM systems depends on the FM/AFM exchange coupling, as well as on setting of AFM grains, achieved either by annealing or deposition in applied magnetic field. Polarised neutron reflectometry provides a way to get structural and magnetic depth profiles at the FM/AFM interface, as well as to determine net orientation of the AFM lattice. We propose to investigate {Ta/Ru seed / AFM IrMn / FM (Co, CoFe)} superlattices. The pinning strength of the samples with pure Co decreases much faster with annealing than that with CoFe samples. By comparing the two types of multilayers annealed at different temperatures, we shall be able to determine the main mechanisms behind the pinning strength degradation.

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For the experiment we have grown a series of samples with nominal composition Ta(2nm)/Ru(2.5nm)/$IrMn_3Cr_{0.05}$(4nm)/FM(3nm)/Ru(3nm) (FM=Co, Fe, and $Co_{70}Fe_{30}$). In addition to the declared in the proposal systems with Co and CoFe we have additionally prepared systems with iron layers. After deposition, part of the samples were annealed at the applied field of 0.18T at a range of temperatures from 100°C to 300°C. Magnetization measurements were performed in an extraction magnetometer (BH looper, results in Table 1).

Table 1. Magnetic properties of the samples: m_m is the magnetic moment divided on sample area, H_c and H_{eb} are coercivity and exchange bias field.

Sample ID	FM	Annealed	m_m (10^{-4}emu/cm^2)	H_c(kOe)	H_{eb} (kOe)
s09	CoFe	No	5.4	0.435	N/A
s05		250°C	5.1	0.405	-1.452
s01		300°C	5.3	0.578	-1.371
s11	Co	No	4.7	0.134	N/A
s07		250°C	4.6	0.078	-0.636
s03		300°C	4.3	0.078	-0.645
s10	Fe	No	5.1	0.346	N/A
s06		250°C	4.6	0.289	-0.922
s02		300°C	3.6	0.219	-0.804

The experiment has been performed at the Super-ADAM reflectometer at room temperature. For the experiment we have used polarized beam. Analyzer was also used for a part of time to check magnetization reversal of part of the samples. Fig. 1 shows the PNR data of the pristine sample with CoFe layer together with preliminary data analysis. As it follows from the fit the nuclear potential of the AFM layer is not homogeneous: close to the IrMn/Ru interface it is of order of 0.6x10^{-4} nm^{-2} and decreasing to value of -0.4x10^{-4} nm^{-2} at the CoFe/IrMn interface.

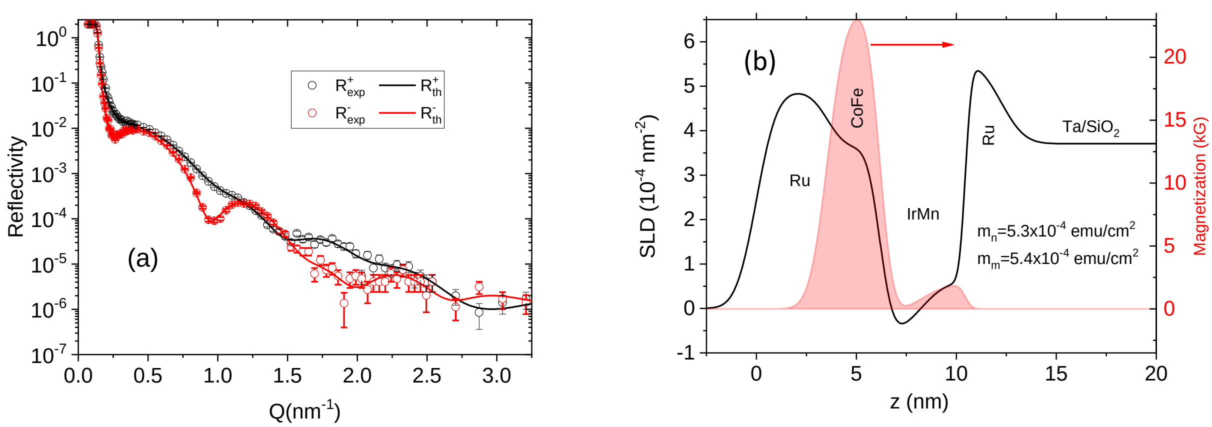

Fig. 1. Experimental (dots) and model (solid lines) reflectivities (a) for sample s09. The corresponding depth profiles of nuclear SLD (black) and magnetization (red) are shown in (b). The area of the curve under the magnetization depth profile filled with red gives the integrated moment of m_n=5.3x10^{-4}emu/cm^2

Fig. 2 shows the spin asymmetries before and after annealing. One can see increase of the first and suppression of the second maxima of SA of the sample s01 annealed at 300°C. The model calculation shows that such a behavior can be described by a change in both nuclear and magnetic potentials (Fig. 2b). In particular, one can see that the SLD of the upper ruthenium layer and the FM layer are 3% and 10% decreased while the SLD of the AFM layer is 20%-30% increased. At the same time, the magnetization of the FM layer decreases by 5%, while the average moment of the AFM layer near the interface with the lower ruthenium grows.

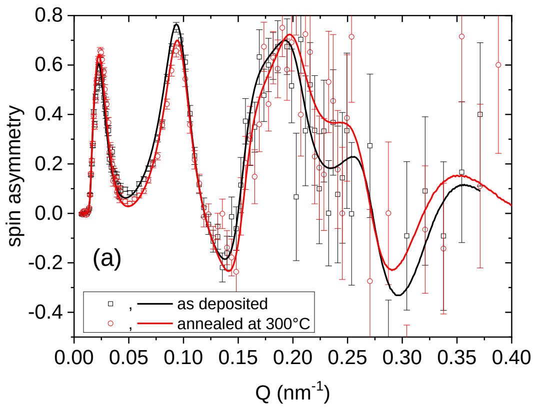

Fig. 2. (a) Experimental (dots) and model (solid lines) spin asymmetries of the pristine (s09, black) and 300°C annealed (s01, red) samples. (b) Corresponding nuclear (solid lines) and magnetization (dashed lines) depth profiles before and after annealing.

We can preliminarily assume the changes in the chemical and magnetic profiles are associated with the diffusion of manganese to the surface, previously observed by J.H. Lee et al (JAP 91, JAP 92). Samples with Co layers showed similar behavior upon annealing, while the Fe samples were shown to have a much stronger diffusion effect (Fig. 3).

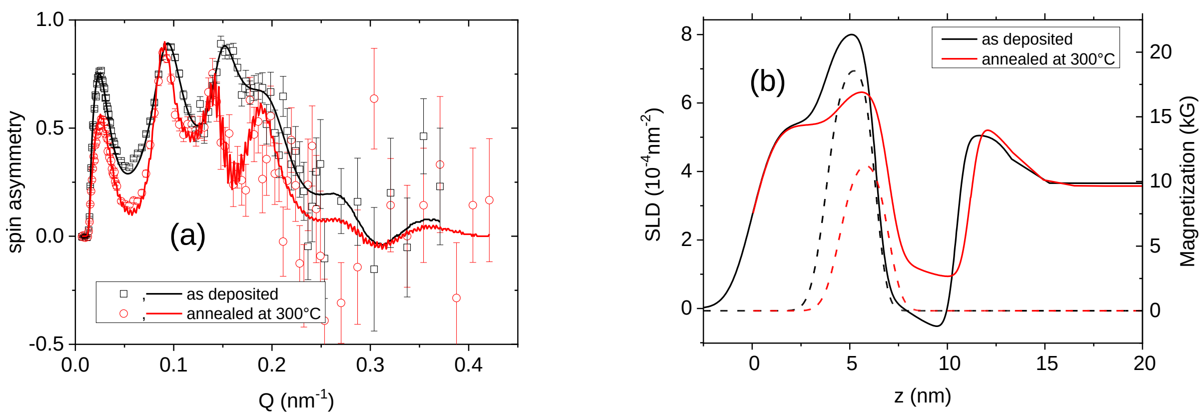

Fig. 3. (a) Experimental (dots) and model (solid lines) spin asymmetries of the pristine (s10, black) and 300°C annealed (s02, red) samples with Fe layer. (b) Corresponding nuclear and magnetization depth profiles before and after annealing.

In conclusion, the conducted PNR experiment allowed us to obtain depth-resolved chemical and magnetic profiles taking place at the AF/FM interface with different ferromagnetic materials. A more detailed analysis of neutron data with involvement of complementary techniques (XRR/RBS/SNMS) follows.