Frequency of magnetization reversal of grains NiFe and IrMn in exchange-biased thin films NiFe/Cu/IrMn

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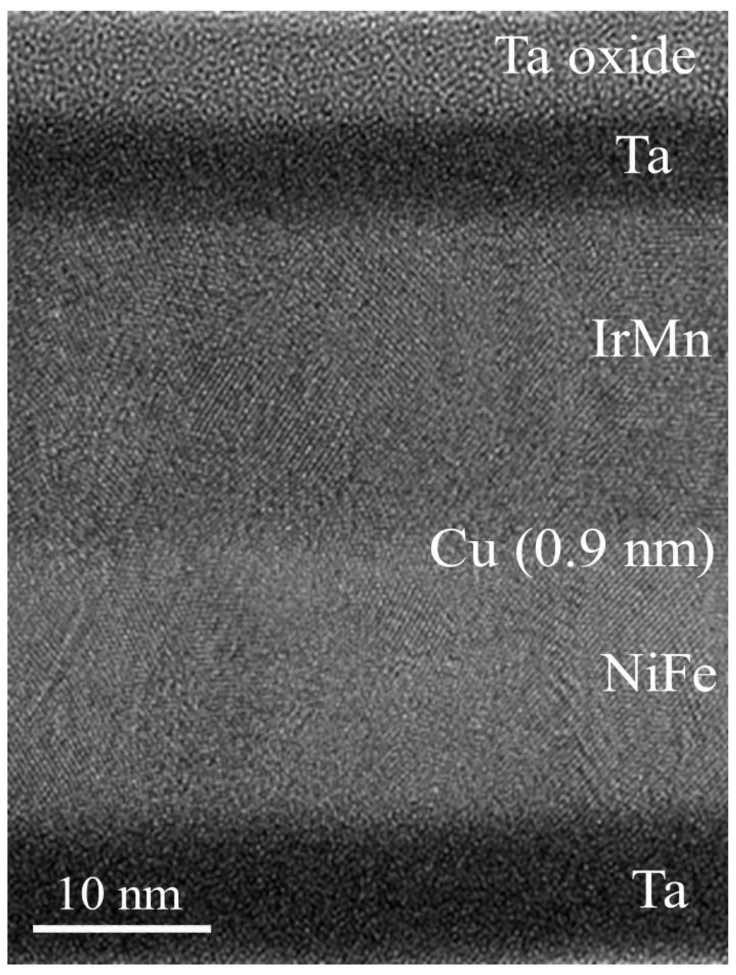
Motivation

NiFe/SL/IrMn heterostructures with a variable spacer layer (SL) thickness are widely used as active elements of magnetic sensors and magnetic memory devices, in which, by changing the SL thickness, it is possible to vary the operating range of finished devices. Understanding the behavior of the magnetization reversal frequencies of FM and AFM grains and establishing the behavior of the exchange bias effect in them is a topical problem in the fields of magnetic sensing and information recording.

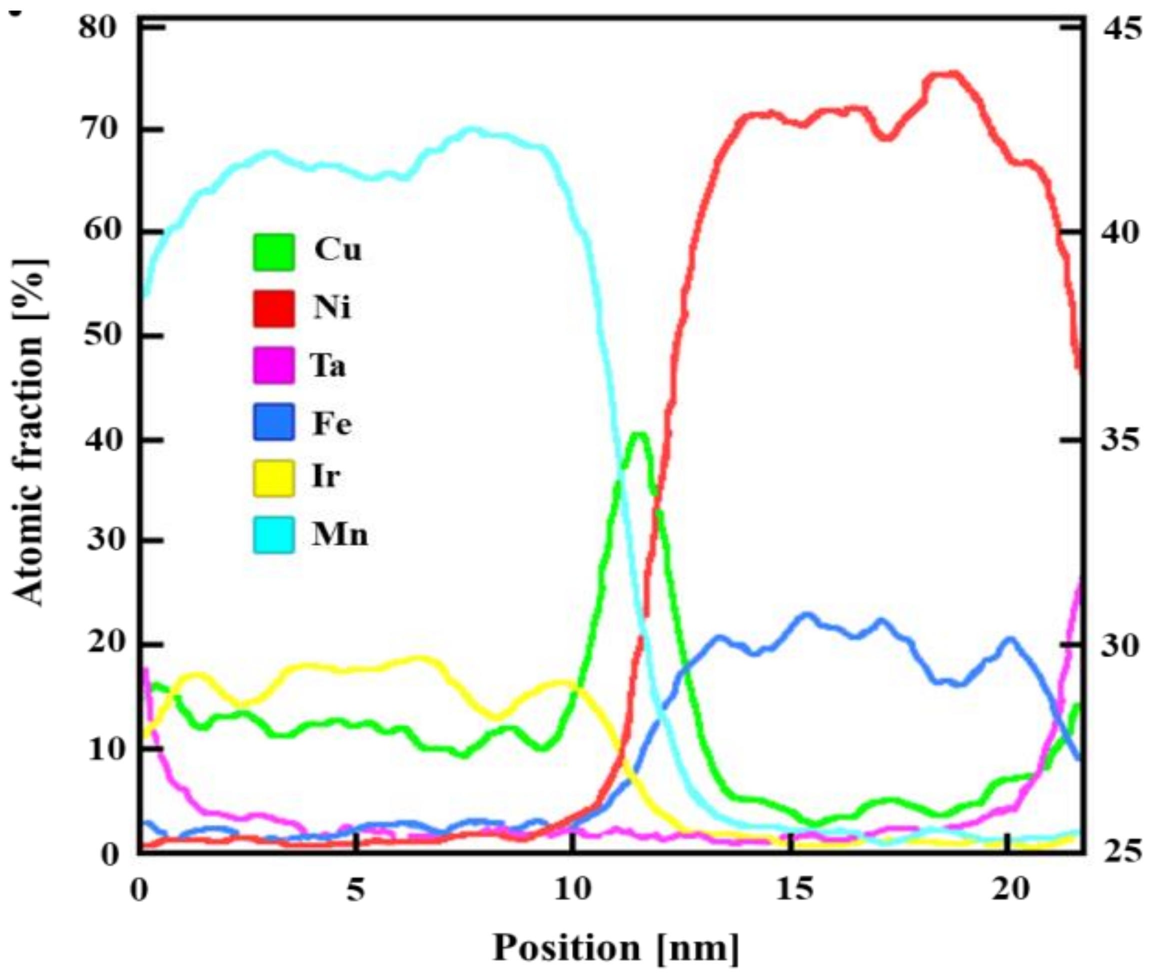
Objective

Identification of the relation between structural modifications of the FM and AFM layers associated with the introducing of the non-magnetic spacer with variations of grain magnetization relaxation frequencies mediated by the unidirectional and rotatable components of the reduced exchange bias in NiFe/Cu/IrMn.

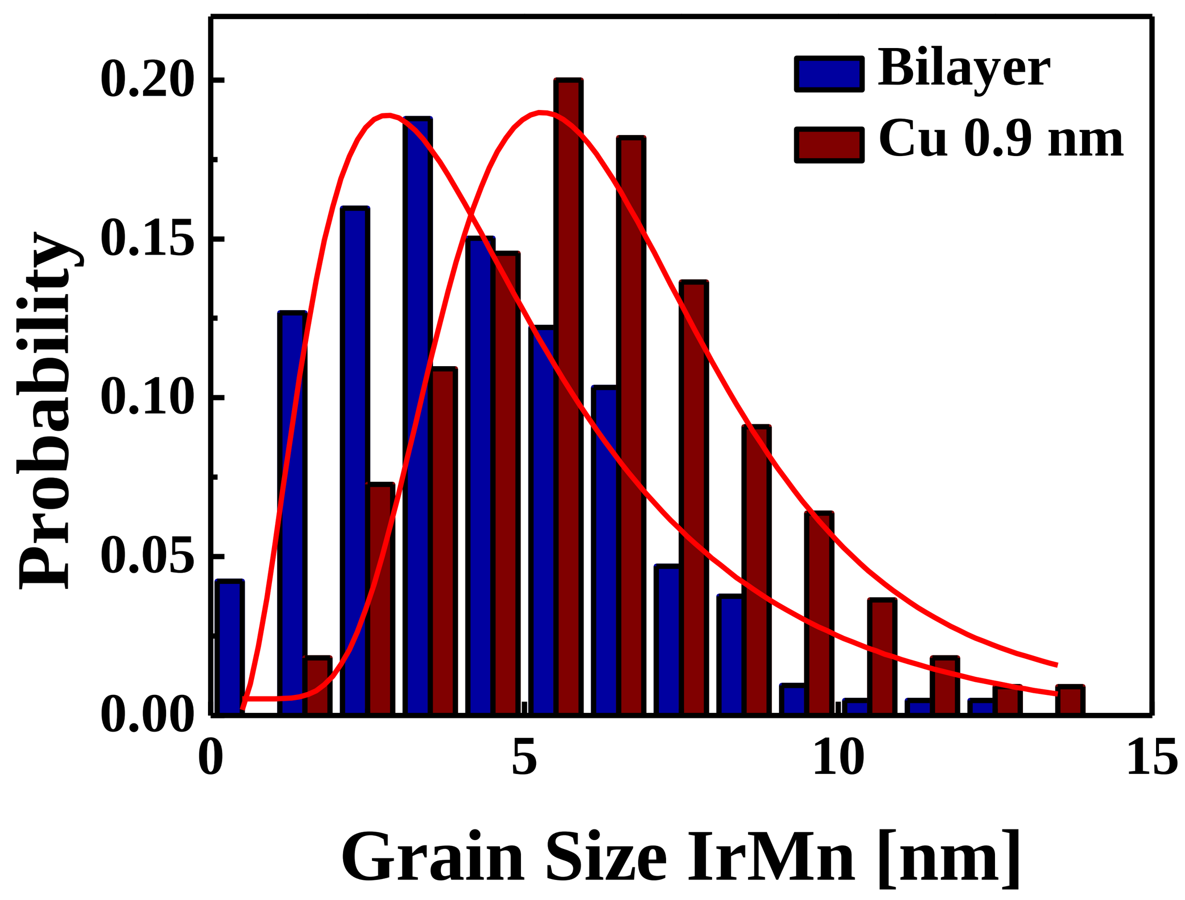
Structure of NiFe/Cu/IrMn samples



TEM images of the cross section of a sample with copper 0.9 nm thickness

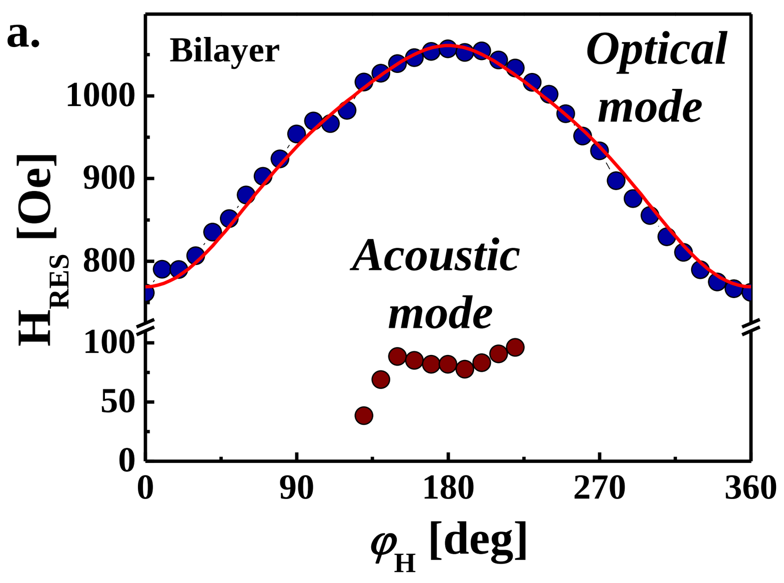


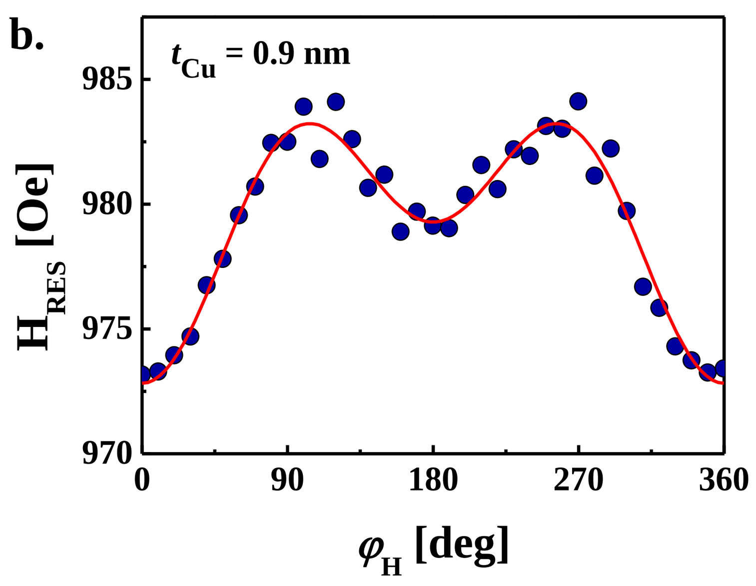
The lateral EDX profiles across the layers of the structure averaged for the entire cross-section area within the imaging window.



Comparison between the grain size distributions in the NiFe and IrMn layers. Solid lines are approximations by log-normal functions.

The effect of t_{Cu} on the characteristic fields of the dynamic magnetization reversal





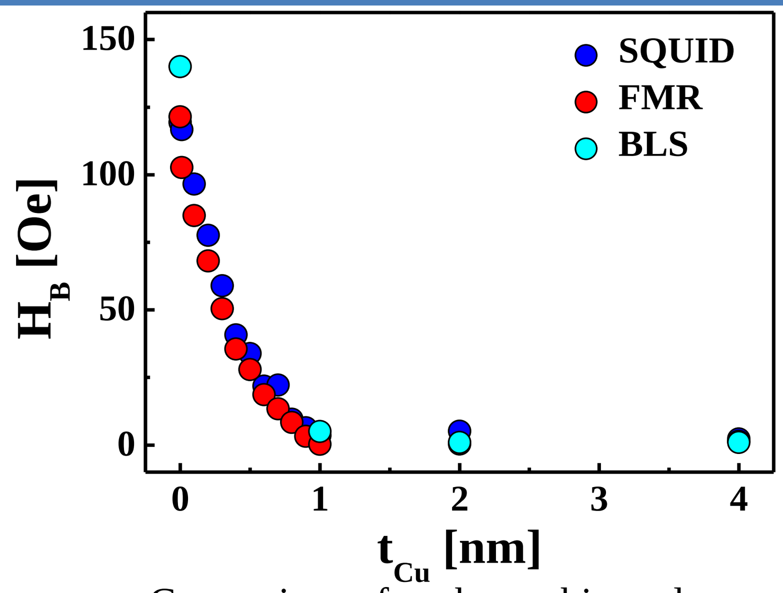
Azimuthal angular dependences of FMR resonant field for the optical and acoustic modes of the FMR in the NiFe/Cu/IrMn exchange biased trilayers for a range of Cu thickness t_{Cu} = 0 nm (a) and 0.9 nm (b).

Solid line on the angular dependence of the FMR in are approximations by equation:

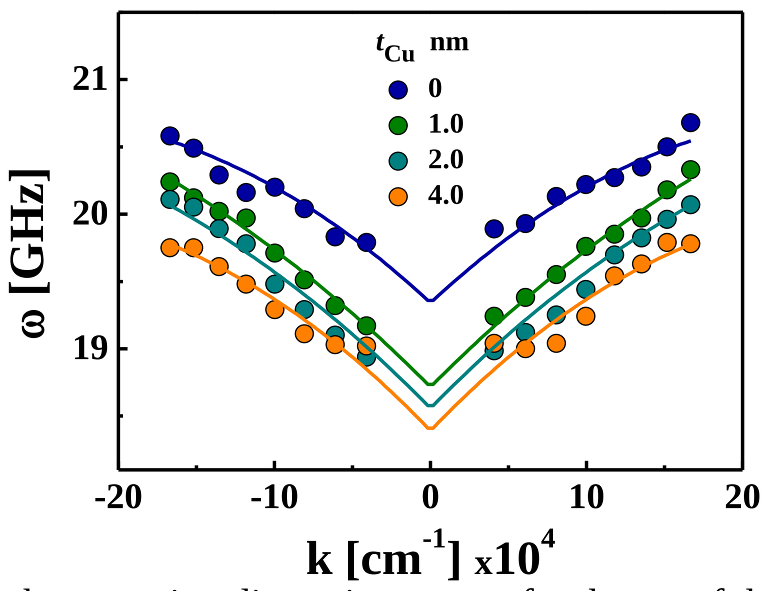
$$H_{RES}=\frac{1}{2}\Big[H_U\big(1-3\cos^2(\varphi_H-\varphi_M)\big)-4\pi M_{eff}-2H_{RA}-H_1^{eff}-H_2^{eff}+\sqrt{\left[H_U\sin^2(\varphi_H-\varphi_M)+4\pi M_{eff}+H_1^{eff}-H_2^{eff}+4\left(\frac{\omega}{\gamma}\right)^2\right]}\Big]$$

Solid line on the dependence of the frequency on the BLS wavenumber are approximations by equation:

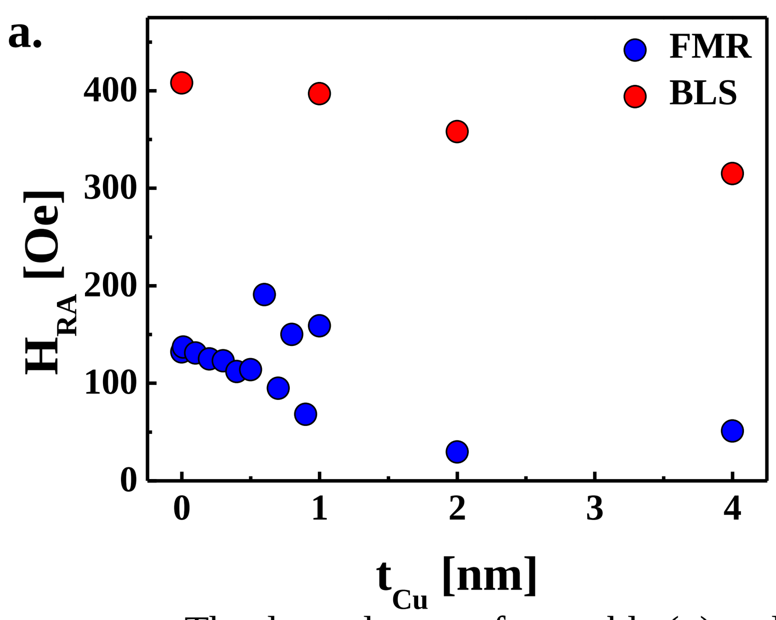
$$\left(\frac{\omega}{\gamma}\right)^2=\left[H+H_U+H_{RA}+2\pi M_S k t_{FM}+Dk^2+\frac{H_W}{(H_W/H_B)+1}\right]\times\left[H+4\pi M_{eff}+H_U+H_{RA}-2\pi M_S k t_{FM}+Dk^2+\frac{H_W}{(H_W/H_B)+1}\right]$$

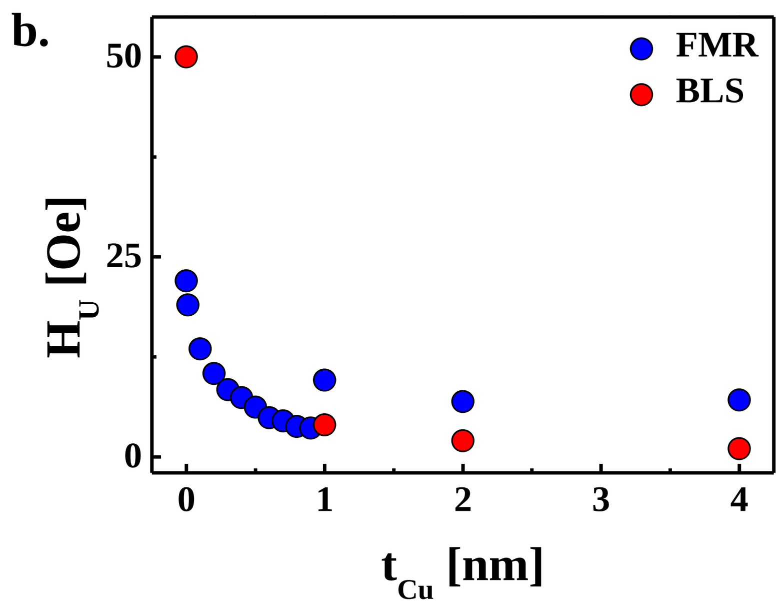


Comparison of exchange bias values characterized by static and dynamic techniques.



Brillouin light scattering dispersion curves for the set of the NiFe/Cu/IrMn trilayers with variable Cu thickness within 0 nm – 4.0 nm range.

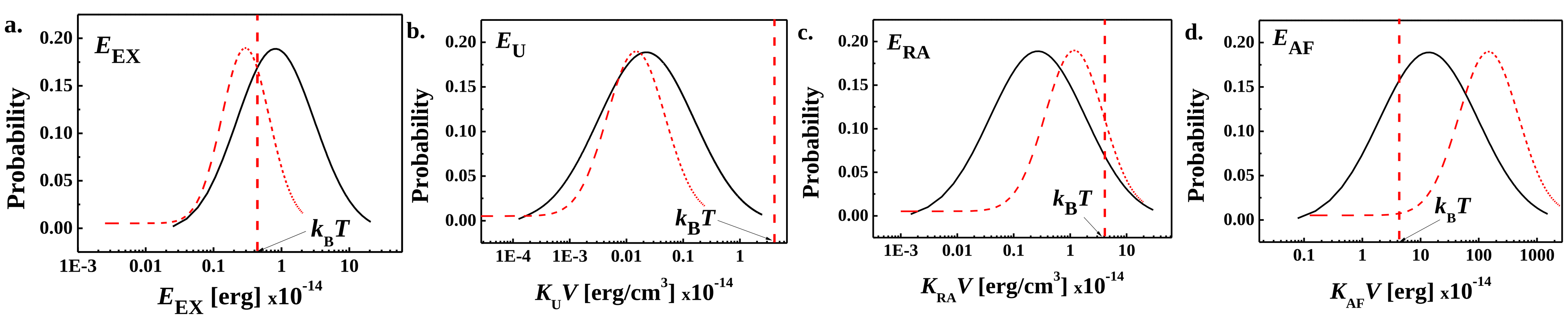




The dependences of rotatable (*a*) and uniaxial (*b*) anisotropy fields on the thickness t_{Cu}.

Non-magnetic spacer thickness effect on interfacial grain magnetization reversal timeframes

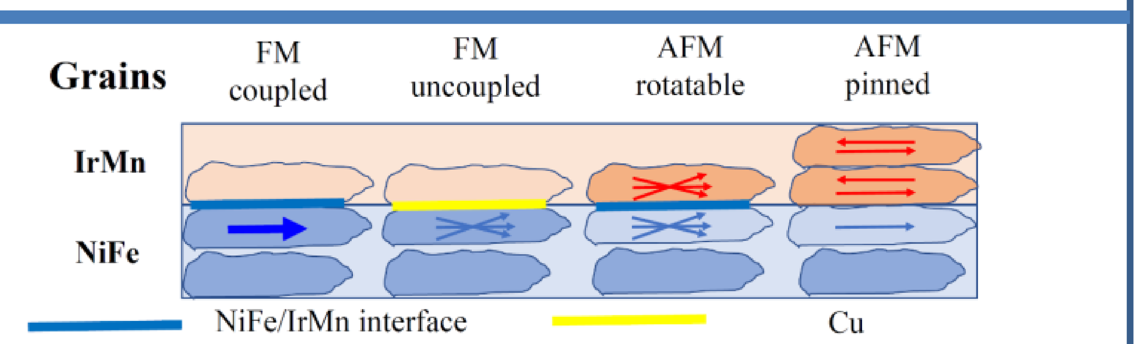
Four types of NiFe/Cu/IrMn interfacial grains: coupled FM (E_{EX}), uncoupled FM (E_U), rotatable AFM (E_{RA}) and pinned AFM (E_{AF}):

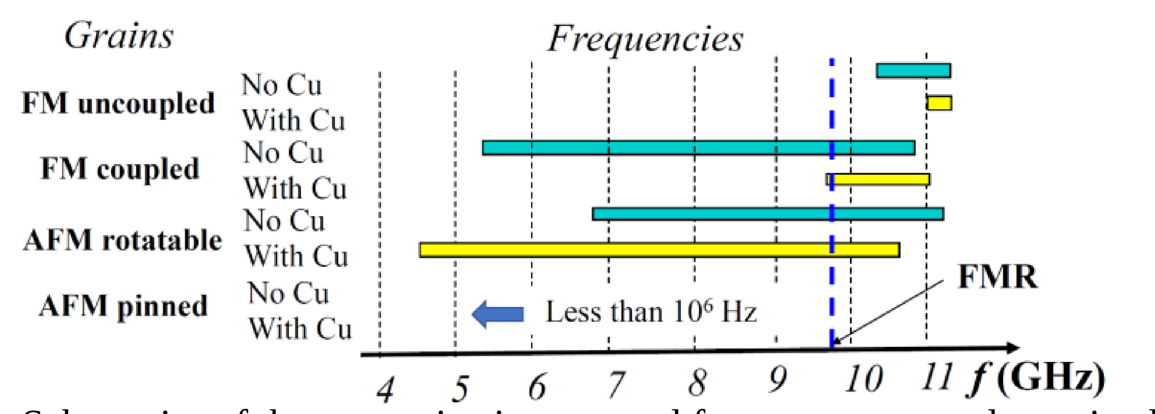


Distributions of grain areas, grain volumes and the grain magnetization reversal energy barriers. Magnetization reversal barrier energy distributions calculated for four types grains at the NiFe/IrMn interface: (a) FM coupled, (b) FM uncoupled, (c) AFM rotatable, (d) AFM pinned.

$$E_{EX} = (1/2)\,(H_U M_S V) + (1/2)\,(H_{EX} M_S S)$$

$$E_U = (1/2)\,(H_U M_S V) \qquad E_{RA} = (1/2)\,(H_{RA} M_S V) \qquad E_{AF} = K_{AF} V$$





Schematics of the magnetization reversal frequency ranges determined from FWHM of the grain magnetization reversal energy barrier distributions.

Conclusions

1. **Addition of a non-magnetic Cu spacer of tCu = 0.9 nm thickness results in the narrowing of grain size distribution in the IrMn layer, enhancement of the mean grain size by ~1.5 times, and reduction of both uniaxial and unidirectional anisotropy constants by 8 times . For the coupled grains in the NiFe layer, the last one results in a shift of the frequency of the magnetization reversal from the 10 GHz (observable by FMR) to the frequencies higher than 10 GHz at tCu = 0.9 nm. This effect is provided by a change in the type of grains dominantly contributing to FMR, namely, from the coupled FM grains for lower Cu thicknesses (<0.5 nm) to rotatable FM and AFM grains for higher thickness of Cu.**
2. **Analysis of the uncoupling effects by the BLS technique sensitive to the interfacial spin wave dynamics reveals similarity between the grain magnetization reversal energy barriers determined independently by FMR and BLS. This evidences the dominance of the interfacial grain contribution to spin wave dynamics throughout the entire range of the Cu thickness from fully coupled NiFe/IrMn interfaces to the fully uncoupled ones.**