Spiral Spin Structure in Dy-Doped Spinel-Ferrite

Anupam K. Singh[1,2], Katayoon Mohseni[1], Verena Ney[2], Andreas Ney[2], Arthur Ernst[2], Malleshwararao Tangi[1], Yicheng Guan[1], Ilya Kostanvoskiy[1], Mostafa I. S. Marzouk[1], Manuel Valvidares[3], Pierluigi Gargiani[3], J. M. Tonnerre[4], Holger L. Meyerheim[1] and Stuart S. P. Parkin[1]

[1]Max Planck Institute of Microstructure Physics, Weinberg 2, 06120, Halle (Saale), Germany
[2]Johannes Kepler University Linz, Altenberger Straße 69, 4040 Linz, Austria
[3]ALBA Synchrotron Light Source, E-08290 Cerdanyola del Valle`s, Barcelona, Spain
[4]Institut Neel, CNRS et Universite Joseph Fourier, BP. 166, 38042 Grenoble Cedex 9, France

ABSTRACT

Noncollinear spin structures have received tremendous interest in recent years as they provide a versatile platform for spin control and manipulation desirable for spintronics[1]. Realization of noncollinearity in ferrimagnetic insulators is of particular interest as the combined effect of both ferro- and antiferromagnetic orders opens up opportunities for their potential utilization in low-damping spintronic devices with desirable magnetic order and minimal stray fields[2]. Inverse spinel nickel ferrite is a classical ferrimagnetic insulator with a collinear in-plane magnetic structure[3]. The substitution of Zn and Al in the nickel ferrite (NiZAF) makes it an excellent choice especially for low-damping spintronics[4]. However, the realization of noncollinearity together with low-damping has remained challenging so far. Here we show the evidence of noncollinearity in the ultrathin films (3-5 nm thickness) of NiZAF induced by the rare earth ion Dy^{3+}-doping. Motivated by our in-house laboratory measurements (SQUID and MOKE) and XMCD experiments using synchrotron x-rays, we performed **soft x-ray resonant magnetic reflectivity** (XRMR)[5] and related simulations to probe the magnetic depth profile. The magnetic asymmetry analysis for the Fe-L_3 edge (Fig. **1a)** using Dyna software shows nice agreement for a model considering an in-plane spiral-type spin structure with weak out-of-plane magnetization component, confirming the noncollinear (and noncoplanar) spin-configuration in the Dy-doped NiZAF. This spiral spin structure for the Fe-spins is sketched in Fig. **1b**. We attribute the stabilization of such noncollinearity to the formation of a local strain field created by the Dy^{3+} (evidenced by Dy-L_3 EXAFS analysis) thereby involving local space-inversion symmetry breaking and emergence of asymmetric Dzyaloshinskii-Moriya interaction. This is supported by our first-principle DFT calculations. The realization of noncollinear spin structure in the insulating spinel-ferrite opens further pathway to explore the possibility of chiral magnetic domain and topological spin textures (e. g., skyrmions) potential for the oxide-based spintronic applications.

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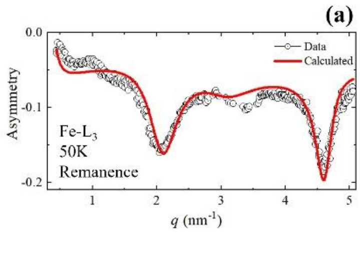

Fe-L3 50 K, Remanence			
No. of layer	Thickness (Å)	OOP φ (deg)	IP γ (deg)
1/top	4.5	18	23
2	6	16	43
3	5.9	6	53
4	4.8	6	99
5/interface	4.8	-33	108

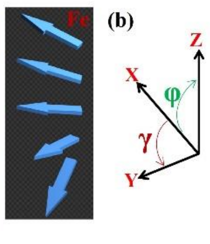

Fig. 1. (a) Magnetic asymmetry fitting (refined parameters are shown right-side) at 50 K for the Fe-L_3 edge in the remanence state for 5% Dy-doped sample. **(b)** Schematic view of spin structure for Fe where axis model is shown.

REFERENCES

[1]. A. Fert, N. Reyren and V. Cros, *Nat. Rev. Mater.* **2**, 17031 (2017). [2]. S. K. Kim *et al. Nat. Mater.* **21**, 24-34 (2022).
[3]. Y. Yafet and C. Kittel, *Phys. Rev.* **87**, 290-294 (1952). [4]. S. Emori *et al.*, *Adv. Mater.* **29**, 1701130 (2017).
[5]. J.-M. Tonnerre *et al., Eur. Phys. J. -Spec. Top.* **208**, 177-187 (2012).