BL-16A/2021G501

Magnetic Properties of MnSi Thin-film using X-Ray Magnetic Circular Dichroism

R. DAWN[1], A. KUMARI[1], M.ZZAMAN[1], V K. VERMA[2] and K. AMEMIYA[3], V. R. SINGH[1]*

[1]Department of Physics, Central University of South Bihar, Gaya 824236

[2]Department of Physics, Madanapalle Institute of Technology & Science Angallu, Madanapalle, AP 517325

[3]Photon Factory, IMSS, High Energy Accelerator Research Organization, Tsukuba, Ibaraki 305-0801, Japan

1. INTRODUCTION: Topologically preserved chiral skyrmions possess a vortex-like nontrivial swirling spin texture, where magnetic spins stabilized by Dzyaloshinskii–Moriya interaction (DMI) aligned in a non-collinear manner acquiring a spherical region. This complex spin texture has gathered massive attraction throughout the last decade due to its intriguing physical properties for both fundamental research and possible applications in storage technology in near future. With a comparison to magnetic domain walls, skyrmion domains exhibit stable current-driven motion at remarkably low current density, enabling low-power consumption spintronic devices [1]. MnSi with a non-centrosymmetric B20 phase is an archetypal helimagnetic material having a skyrmionic lattice, which has a vast exploration in both theoretical and experimental applications for decades. In a skyrmionic lattice of MnSi, spin transfer torque (STT) is observed, leading it to the injection of spin-polarized currents. In particular, the skyrmion size of MnSi ranges from few (~10-20) nm, which is considered small among well-known groups with skyrmion spin textures. STT tends to increase significantly with reducing skyrmion size [2]. Although material parameters affect the skyrmion size, DMI and ferromagnetic exchange interaction mainly contribute to determining the skyrmion size. In this regard, MnSi has excellent prospects as a good candidate for applied physics. In this study, we have presented MnSi as skyrmionics and its structural and electronic analysis through spectroscopic based soft x-ray absorption spectroscopy (XAS) and x-ray magnetic circular dichroism (XMCD) experiments.

2. EXPERIMENT: MnSi films were deposited on c-cut sapphire (Al_2O_3) substrates by direct current (DC)/radio frequency (RF) magnetron sputtering with a base pressure of 1.0×10^{-6} Torr. The MnSi films were grown at room temperature under 10 mTorr Ar pressure by co-sputtering Mn and Si targets for 5 min. The DC power for the Mn target was 10 to 20 W, and the RF power for the Si target was 100 W. Following the deposition of MnSi, the as-grown MnSi was crystallized by inducing an in-situ annealing treatment for 2 hours in the temperature range of 550–590°C. X-ray spectroscopy, scattering, and imaging experiments were performed at the variable-polarization soft x-ray beam-line BL-16A of the Photon Factory (KEK, Japan). Experimental geometry of soft x-ray absorption (XAS) and x-ray magnetic circular dichroism (XMCD) experiments are shown in Fig. 1. The sample was placed in the vacuum chamber with a pressure of 10^{-9} Torr equipped with a 5 T superconducting magnet. XAS and XMCD signals were measured with an energy resolution of 0.1 eV using the surface-sensitive total electron yield (TEY) method near Mn $L_{2,3}$ absorption edges with right and left circularly polarized (RCP and LCP) x-rays.

3.RESULTS AND DISCUSSIONS: **T**he XAS spectra obtained with applied magnetic fields of +2.0 and -2.0 T are denoted by μ^+ and μ^- which represent left and right circularly polarized light, respectively as shown in Fig 1. The XMCD spectrum was recorded by taking a difference between the XAS spectra with negative and positive helicity of the circular polarized light. It is known from literature that, MnSi is a paramagnetic metal that turns into a ferromagnet at cryogenic temperatures below 29 K [3]. Surprisingly, despite the metallic nature of the MnSi thin-film, the Mn absorption shows a multiplet structure at the L_3 and L_2 edges. Well-resolved peaks at the absorption maxima at E = 640.48 eV and 641.87 eV a doublet structure at the L_2 edge, which splits into two maximums at E = 651.16 eV and E = 652.66 eV, are clearly observable. This verifies that the fine structures of Mn $2p \rightarrow 3d$ transition should result from the localization of Mn *3d* electrons rather than the oxidation of the surface. Mn $3d^5$ was assumed as

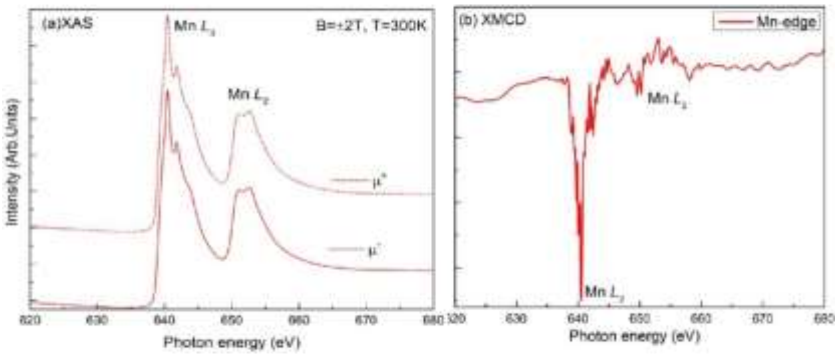

Fig. 1 (a) XAS (b) XMCD of MnSi thin film at Mn-edge.

an initial state and Mn $2p^5 3d^6$ was the final configuration. The observed fine structure of the XAS spectrum of Mn also corresponds to the one calculated from the multiplet effects [Fig. 1(a)]. XMCD signal measured in a magnetic field of B =2.0 T well above the saturation is shown in Fig.1(b) for Mn-edges. Despite that the magnitude of the XMCD measured at the $L_{2,3}$ edges of Mn is clear that the signs of the dichroic signals are the same. The XMCD signal at the Mn L_2 edge is notably suppressed, indicating quenching of the orbital moment [4]. The sum rule analysis allows us to estimate the XMCD intensity to XAS intensity ratio for Mn as 5.77×10^{-3}.

ACKNOWLEDGEMENTS: The experiment at the Photon Factory was approved by the Program Advisory Committee (Proposal Nos. 2021G501. Authors acknowledges support from UGC-BSR Start-up Research Grant F.30-395/2017(BSR).

References:

[1] B. Göbel, I. Mertig and O.A. Tretiakov, Physics Reports (2020).
[2] W.Y. Choi, H-W Bang, S-H Chun, S. Lee, M-H Jung, Nanoscale Res Lett **16**, 1-7 (2021).
[3] V. Ukleev, Y. Yamasaki, D. Morikawa, K. Karube, K. Shibata, Y. Tokunaga, Y. Ok, PHYSICAL REVIEW B **99**, 144408 (2019).
[4] S. L. Zhang, R. Chalasani, A. A. Baker, N.-J. Steinke, A. I. Figueroa, A. Kohn, G. van der Laan, T. Hesjedal, AIP ADVANCES **6**, 015217 (2016).

*Electronic Email: vijayraj@cusb.ac.in