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Tracing magnetic atom diffusion at $Co_3Mn/Mn_{3-\delta}Ga$ interface by XMCD and EXAFS

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Controlling the interfacial properties is an essential issue for developing the spintronics materials because the symmetry-broken interfaces in the magnetic thin films provide some unique properties such as perpendicular magnetic anisotropy (PMA) and exchange coupling between different layers. For the developments of the tunnel magnetoresistance (TMR) devices, the investigations of interfacial abruptness and chemical compositions are strongly required because the TMR ratio is directly influenced by the qualities of interfacial atomic structures.

As promising materials for TMR devices, tetragonal ferromagnetic $Mn_{3-\delta}Ga$ alloys have been extensively investigated because this alloy exhibits high PMA energies of over 1.0 MJ/m^3, low magnetic damping constants, and low saturation magnetizations originating from their ferrimagnetic properties that cause antiferromagnetic coupling at the different Mn sites [1]. Other candidates for the magnetic switching layer combined with the $Mn_{3-\delta}Ga$ layer are the metastable bcc Co_3Mn alloy which exhibits high TMR ratio and compatible to the MgO insulating barrier layer [2]. In particular, perpendicular magnetization switching using Mn-based alloys is strongly demanded for high TMR spintronic devices [3]. However, the interfacial diffusion of Mn atoms has to be pursued explicitly. In this study, we present the XMCD and EXAFS to investigate the element-specific magnetic and structural properties at the bcc $Co_3Mn/Mn_{1.5}Ga$ interfaces with annealing process.

The samples were prepared by magnetron sputtering on MgO (001) substrates. 30-nm-thick $Mn_{61}Ga_{39}$ alloys was grown at RT with the post-annealing at 500°C. Then, 1-nm-thick Co_3Mn layer was deposited with 2-nm-thick MgO capping layer. Three kinds of samples of as-grown and post-annealed at 250 and 350°C were prepared. The XMCD analysis was performed at BL-7A in the Photon Factory at the High-Energy Accelerator Research Organization (KEK-PF). The EXAFS measurements at Co and Ga *K*-edge were performed at BL-12C in KEK-PF using the florescence yield mode with a 19-element solid-state detector at RT.

Figure 1 shows the XAS and XMCD of Mn and Co $L_{2,3}$-edges for as-grown, 250 and 350°C annealing. Metallic line shapes are clearly observed. The XMCD line shapes are also drastically modulated by annealing. The XMCD in 350°C annealing is not explained by the simple sign reversal from the as-grown case, indicating the Mn diffusion and the formation of Co_xMn alloy coupled with MnGa layer anti-ferromagnetically. Element-specific magnetization curves in the Mn and Co L_3-edges along the perpendicular direction also inform us to understand the change of interfacial magnetic coupling, which is similar to the cases of previous Co/MnGa interfacial reaction [4].

Element-specific magnetization (*M-H*) curves in the Mn and Co L_3-edges along the perpendicular direction also exhibit the changes of interfacial magnetic coupling. Both large hysteresis originating from MnGa and the slope from the hard-axis contribution in Co_3Mn are mixed at the as-grown stage. By annealing, the *M-H* curves are drastically modulated, which can be explained by the Mn atom diffusion at the interface. Finally, at the annealing of 350°C, the slope disappeared, suggesting uniform 'inverse PMA' material formation. These findings suggest that the interfacial reaction and magnetic atom diffusion can be probed by XMCD with element-specific *M-H* curves.

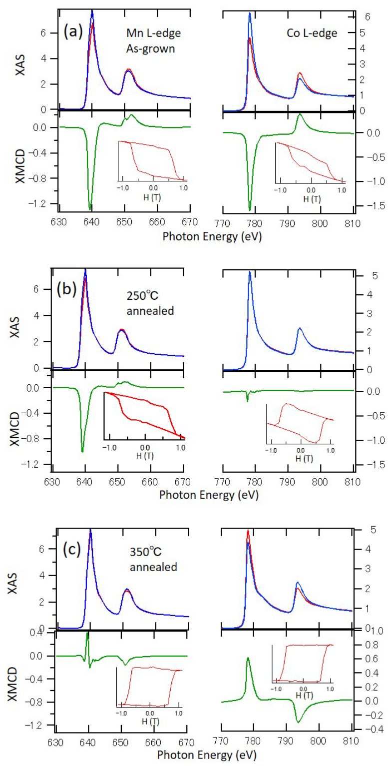

Fig. 1, XAS and XMCD of Mn and Co *L*-edges in Co_3Mn/MnGa with annealing temperature dependence. (a) As-grown, (b) 250°C annealing, and (c) 350°C annealing cases. Insets show the element-specific hysteresis curves at Mn and Co L_3-edges.

References
[1] S. Mizukami *et al*., Scripta Materia **118**, 70 (2016).
[2] K. Kunimatsu *et al.*, Appl. Phys. Exp. **13**, 083007 (2020).
[3] K. Z. Suzuki *et al*. Appl. Phys. Lett. **118**, 172412 (2021).
[4] J. Okabayashi *et al.*, J. Magn. Magn. Mater. **460**, 418 (2018).
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