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Detection of the oxidation state in Ta-O/Co-Fe-B heterostructures by Soft X-ray Absorption Spectroscopy

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1 Introduction

Spin-orbit torque (SOT) induced magnetization switching in oxide/ferromagnetic heterostructures has attracted immense interest owing to its potential for the development of high-performance spintronics devices, realized by tuning the surface oxidization [1]. Our previous research on SOT-induced magnetization reversal in typical Ta-O/Co-Fe-B heterostructures showed a significant contribution of the interface-sensitive SOT effective field, in addition to the bulk-sensitive SOT effective field [2]. However, the understanding on the oxidation state of at the Ta-O/Co-Fe-B interface is still intact.

2 Experiment

To confirm the oxidation state of the surface treated sample, the surface sensitive soft X-ray absorption spectra (XAS) at the oxygen K-edge was conducted at Beamline 7, KEK, Tokyo Univ. The O K-edge XAS were collected for two samples: Ta(2nm)/Co-Fe-B(5nm) and Ta-O(2nm)/Co-Fe-B(5nm), prepared at P_{Oxygen} = 0.3 Pa, using total electron yield as detection (TEY) method. The samples were kept in vacuum condition before the XAS measurement to restrain the oxidation of the CoFeB layer. The energy resolution was about 3000 $E/\Delta E$ at the oxygen K edge. The base pressure of the chamber during the XAS experiments was less than 10^{-7} Pa.

3 Results and Discussion

Fig. 1 shows the XAS spectra at the oxygen K-edge for Ta-(2nm)/CoFeB(5nm) and Ta-O(2nm)/CoFeB(5nm) samples in red and black curves, respectively. The lower energy two peaks at around 531~535 eV and the higher energy peak at around 542 eV could be seen. The former is produced by the transitions of the Oxygen 1s electrons to the 3d levels of Co and/or Fe [3-5], which is correspond to surface CoFeB oxidation layer, while the latter could originate from the Si-O-Si of the SiO_2 substrate [6]. The soft X-ray penetration depth is in the scale of 10 nm; therefore, all the stacking layer could be observed in the sample. Moreover, the inset of Fig. 1 shows the shoulder of the first peak at around 533 eV. In order to visualize the slight oxidation layer on Ta, subtracting the spectrum of sub//Ta-O(2nm)/CoFeB(5nm) sample to that of sub//Ta(2nm)/CoFeB(5nm) sample was carried out. The lower peaks were owing to oxygen 2*p* states hybridized with Ta metal *d*-state and the hybridization peaks split by the crystal field effect. The higher peak was attributed to the oxygen 2p states mixed with metal sp states [7]. The energy position could be identified as Ta_2O_5 [4], even though the peak intensity needs further discussion to assign exactly the Ta oxygen valence state.

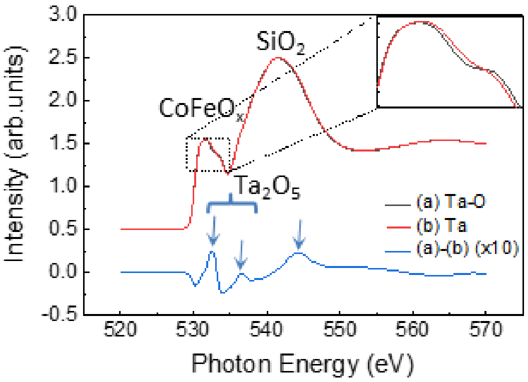

Fig. 1: O K-edge XAS spectra of Ta(2nm)/Co-Fe-B(5nm) (red) and Ta-O(2nm)/Co-Fe-B(5nm) (black). The subtracted curve between two spectra is shown in blue. Inset magnifies the shoulder at 533 eV of the first peak.

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References

[1] H. An et al., *Nat. Commun.* 7, 13069 (2016).
[2] T. V. A. Nguyen, *JSAP Spring Meeting 2021*, 17p-Z19-7, 2021.
[3] C-H. Chen et al., *Jour. Solid State Chem.*, **183**, 27, (2010).
[4] J. C. Jan et al., *Appl. Phys. Lett.* **86**, 161910, (2005).
[5] F. M. F. de Groot et al., *Phys. Rev. B* **40**, 5715, (1989).
[6] A. Marcelli et al., *Journal De Physique* **C8**, 107, (1985).
[7] L. Soriano et al., Solid State Commun., **87**, 699, (1993).

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