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Crystal orientation dependence of XMCD for Fe_3O_4 epitaxial films

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1 Introduction

The tunnel magnetoresistance effect (TMR) is the key technology for the spintronic devices like STT-MRAM. The magnetic tunnel junctions consist of tunnel barrier sandwiched by ferromagnetic electrodes. Since the TMR ratio is determined by the spin polarization of the electrode, developments of the electrode material with large spin polarization is crucial issue in the spintronic research field.

The magnetite, Fe_3O_4, is the most popular ferrite which has spinel crustal structure. It is a ferrimagnetic material and has the electric conductivity at room temperature. By *ab-initio* calculation, it was predicted to have -100% spin polarization, which could lead large TMR ratio [1]. However, such large TMR has not been realized, so far [2].

To clarify the reason of suppression of the TMR in MTJs with Fe_3O_4, we conducted the XMCD measurements for Fe in Fe_3O_4 for various crystal orientations.

2 Experiment

Samples were fabricated by an MBE system. Fe_3O_4 thin films were prepared with three crystal orientations, (001), (110) and (111). The sample structures were MgO(001), MgO(110) or MgO(111) substrate / MgO(20 nm) / NiO(5nm) / Fe_3O_4(60 nm). Following the deposition of MgO buffer layers, NiO layer was inserted to prevent diffusion of Mg from MgO into Fe_3O_4. Fe_3O_4 thin film was formed by reactive deposition at a substrate temperature (T_{sub}) of 300℃ in an O_2 gas atmosphere of 4×10^{-4} Pa. Then the films were annealed at T_{sub} of 600℃ for 30 minutes in an O_2 gas atmosphere. Partial pressure of O_2 gas was 1×10^{-4} Pa. The X- ray absorption spectroscopy (XAS) and XMCD were performed at BL-7A in the Photon Factory (KEK). The total-electron-yield mode was adopted, and all measurements were performed at room temperature and the geometries were set to normal incidence configuration.

3 Results and Discussion

To investigate the magnetic states of iron ion in Fe_3O_4 layer, we performed the XMCD measurements at BL-7A . The sample structure was MgO / Fe_3O_4 / MgO or Al_2O_3 cap layers with various crystal orientations. The measurements were carried out in the magnetic field of 1T at room temperature. The XMCD spectra for Fe_3O_4(001), (110) and (111) were shown in Fig.1 (a), (b) and (c), respectively. The spectra were more complex than that of pure Fe due to multiple cation sites. They consisted of Fe^{3+} in A site, tetrahedral site, and Fe^{2+} and Fe^{3+} in B site, Octahedral site. The magnetic moment of Fe ions in A site and those in B site aligned antiferromagnetically due to super exchange coupling. Although all the spectra were similar, it should be noted that each structure were different in detail. The rate of occupation will be determined by the ligand field multiplet analysis of XMCD shape in principle.

Fig.1(d) shows the TMR curve of Fe_3O_4(001) / MgO(001) / Fe magnetic tunnel junctions at 80K. The inverse TMR of -55.8% was observed [3]. That is the largest TMR ratio in Fe_3O_4-MTJs so far, and the negative sign of the TMR ratio corresponding to the theoretical prediction. The gradual change of the tunnel resistance in high magnetic field indicated that the antiparallel magnetic configuration was not realized. Though the reason has not been clarified yet, the imperfect antiparallel configuration could attribute to the antiphase boundary or interface magnetic characteristics at Fe_3O_4/MgO interface.

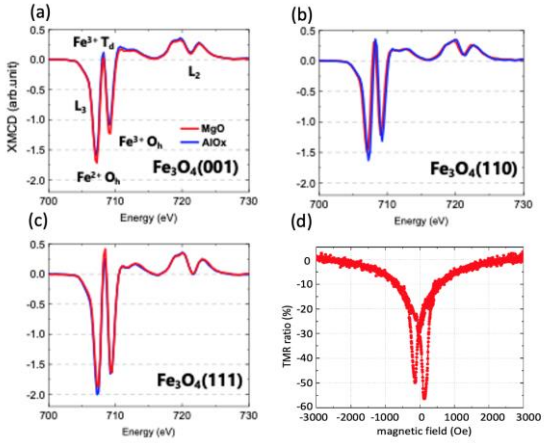

Fig.1 XMCD spectrum of (a) MgO(001)/Fe_3O_4, (b) MgO(110)/Fe_3O_4, (c) MgO(111)/Fe_3O_4. (d) TMR curve of Fe_3O_4(60 nm) / MgO(2.5nm) / Fe(10nm)/Au(30nm) at 80K.

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