Topotactic phase transformation of spinel Fe_3O_4 to FeO with rock salt structure via ion irradiation

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Introduction

An interesting topic of recent study is how spinel materials, such as $MgAl_2O_4$, $MgGa_2O_4$ and $MgIn_2O_4$[1], are affected by ion implantation, a technique which can change a material's fundamental properties. However, hardly any investigation has been carried out on irradiated spinel ferrite materials. In a previous study, we investigated the effect of Kr ion implantation on the epitaxial growth $CoFe_2O_4$ thin films, and found that the magnetization decreased due to ion irradiation causing a structural transformation from spinel to rock salt type. However, the mechanism of topotactic reaction in epitaxial films was not well explained. In this study, we focus on prototype spinel Fe_3O_4 thin films and investigate the structural transformation from spinel to rock salt via Kr ion implantation.

Experiment

Fe_3O_4 thin films were fabricated on MgO (001) single crystal substrates by reactive RF sputtering. The substrate temperature was kept at 300℃. Kr ions were accelerated in a conventional ion implantation system in Nanotechnology Platform. The acceleration was set at 30 keV and the ion dosage was controlled at 5×10^{15} ions/cm^2. An annular 25% ^{57}Fe enriched tablet placed on a natural Fe sputtering target was custom-made in order to perform room temperature conversion electron Mössbauer spectroscopy (CEMS). The structure transformation was measured by X-ray diffraction at beamline BL-4C of the Photon Factory, KEK, while the magnetization was measured by vibrating sample magnetometer (VSM) at room temperature.

Results

Figure 1 and Figure 2 show the result of the (0 0 *l*) scan, which defined with MgO lattice, of sample after 5×10^{15} ions/cm^2 ion irradiation. In Fig.1, the intensity of strongest peak (partial shown) indicates the reflection of the substrate, MgO (0 0 2). The protuberant part on the right side of MgO (0 0 2) peak, shown by the arrow represents the thin film. From the lattice constant value, we estimated that the thin film observed is Fe_3O_4 (0 0 4). In Fig. 2, the reflection of the MgO (0 0 2) substrate is also observed as the peak of strongest intensity, the arrow indicating the slight swell on the left side of the MgO (0 0 2) peak (shown by the arrow) indicates the presence of FeO (0 0 2) thin film, as estimated from lattice constant.

From these results we understand that after ion irradiation, the spinel structure of Fe_3O_4 changes to the rock salt structure of FeO. However, some Fe_3O_4 remains. In other words, the structural transformation is partial, both Fe_3O_4 and FeO can be observed in the irradiated sample. We consider that this incomplete change is due to ion irradiation not being enough to affect all parts of the thick Fe_3O_4 thin film. To solve this issue, we will fabricate thinner films of about 15 nm thickness.

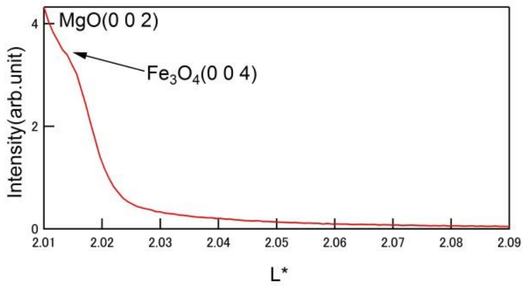

Fig. 1. The result of the (0 0 *l*) defined with MgO lattice, which shows Fe_3O_4 (0 0 4) after 5×10^{15} ions/cm^2 ion irradiation.

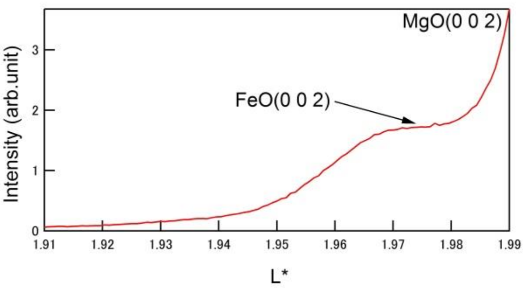

Fig. 2. The result of the reciprocal lattice indexes defined with MgO lattice, which shows FeO (0 0 2) thin film after 5×10^{15} ions/cm^2 ion irradiation.

1) B.P. Uberuga *et al., Nat. Commun.*, 6 (2015)