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Magnetic Modification at Sub-Surface of FeRh Bulk by Energetic Ion Beam Irradiation

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1 Introduction

Fe50Rh50 alloy with B2 (CsCl-type) crystal structure has a unique magnetic behavior of a first order antiferromagnetic-ferromagnetic phase transition at about 310 K [1,2]. The authors previously reported that the magnetic state (antiferromagnetic, ferromagnetic and paramagnetic) of FeRh could be designedly controlled by ion beam irradiation with various energies and ion species [3]. According to those experimental evidences, the change in magnetization of FeRh by using ion beam irradiation is deductively dominated by the energy deposition through elastic collisions between the ions and the samples that introduces the lattice defects in FeRh [4]. The unit energy deposited in the materials through the interaction with the ion beam can be calculated by using Transport of Ions in Matter (TRIM) simulation. Deposition energy through the elastic collisions usually depends on a kind of ion and penetration depth, and large energy is given to the materials just before the penetrate ion stops.

In the present study, we have tried to modify the subsurface of FeRh from AF to FM by using ion beam irradiation. As the result of TRIM-code 2008, deposition energy can be introduced in the sub-surface of FeRh by using high energy ion beam. So, it must be a reasonable idea to introduce FM layer only in such range by controlling the deposition energy. We also previously reported that we succeeded to fabricate micro scale magnetic patterns using the high energy ion microbeam technique [5]. If we succeed to modify in the sub-surface of FeRh, it will be possible to control the three-dimensional magnetic patterning by combining these techniques.

2 Experiment

In order to make such irradiation induced ferromagnetic layer, FeRh bulk samples were irradiated with 2.9 MeV He and 5.9 MeV He ion beams. Since such ion beams can effectively deposit the elastic collision energy in the ranging from 3 to 5 μm and 10–12.5 μm from the surface in accordance with the TRIM simulation, respectively. The magnetic state was evaluated by using SQUID magnetometer and Fe L-edge XMCD measurement at BL16A in KEK-PF. Since the penetration depth of soft X-ray is considered to be about 2 nm, XMCD observation gives the information of magnetic moments at the sample surface. We can obtain the information whether it is possible to modify the sub-surface of FeRh or not when we compare the result of these measurements.

3 Results and Discussion

Figure 1 shows the magnetic-hysteresis loops measured at 5K for the unirradiated and irradiated samples with 2.9MeV and 5.9MeV He ion with the ion fluence of 2×10^{14} cm^{-2}. As can be seen in the figure, the saturation magnetization for the unirradiated sample is 0 emu/cc, in contrast that the irradiated samples show some extent. The saturation magnetization values for the irradiated samples were calculated based on the area in which the elastic irradiation energy deposited, that is, simply from 3 to 5 μm depth region for the 2.9MeV He ion irradiated samples, and 10–12.5 μm depth region for the 5.9MeV He ion irradiated samples. Hence, the saturation magnetization is determined to be 320 emu/cc for the 2.9 MeV sample, and 280 emu/cc for the 5.9MeV samples. These values seem to be quite low in comparison to literature values for ferromagnetic FeRh.

The relationship between the deposition energy and the saturation magnetization for the irradiated FeRh samples with 30 keV Ga ion beam with various ion fluences is indicated in Fig. 2, which is obtained from our previous study. As is discussed in the Experimental Procedure section, the two samples (2.9MeV and 5.9MeV He irradiated samples) were irradiated with the same irradiation fluence of 2×10^{14} cm^{-2}. However of this, the energy deposited in the each sample is a little but different. This is because the energy deposition regions are different, which cause the difference in the energy deposited, 9.4×10^{12} keV/μg (2.9MeV) and 7.7×10^{12} keV/μg (5.9MeV). As can be seen in the figure, the both plots seem to quite well fit to the curve drawn from the irradiated sample with 30 keV Ga ion beam. This simply

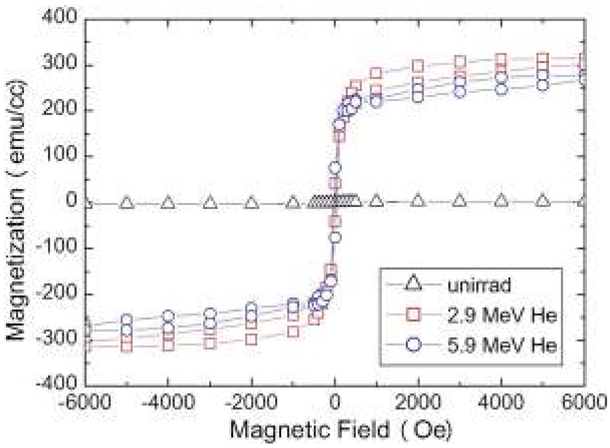

Fig. 1: M-H curves at 5K for the unirradiated and irradiated samples.

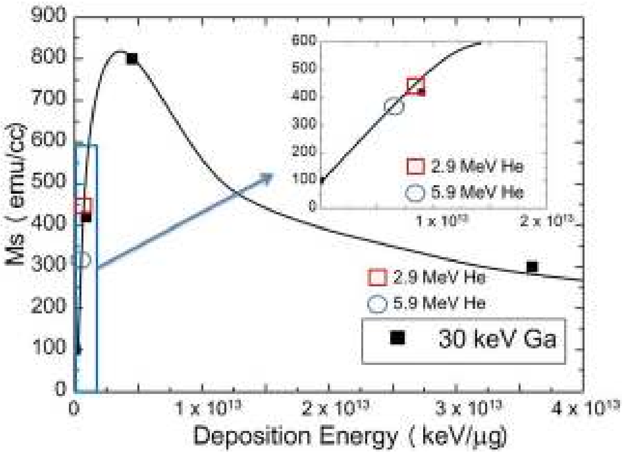

Fig. 2: Relationship between deposition energy and saturation magnetization of the FeRh samples.

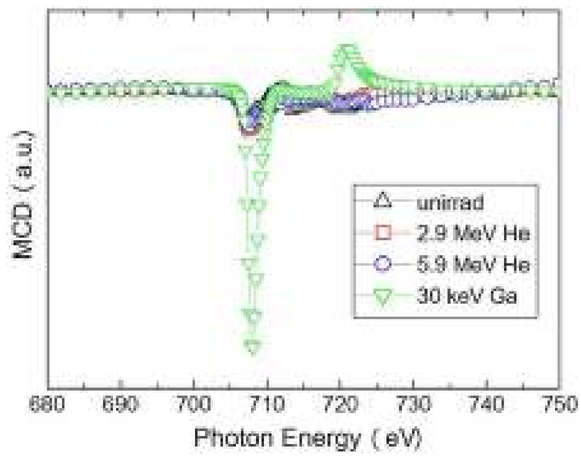

Fig. 3: XMCD spectra for the unirradiated and irradiated samples.

indicates that the ion beam irradiation induced ferromagnetism in FeRh can be considered in the same way as 30 keV Ga ion beam case, even when we try to modify the sub-surface of the samples. Then, the irradiation induced FM in the present samples has not yet been fully ferromagnetically spin aligned in the present irradiation condition employed.

Figure 3 shows the XMCD spectra at the Fe L_3- and L_2-edges for the unirradiated sample and the irradiated samples with 2.9 and 5.9MeV He ion beam with the ion fluence of $2x10^{14}$ cm^{-2}. The data for the irradiated thin film samples with 30 keV Ga ion of the ion fluence of $1x10^{13}$ cm^{-2} are also plotted for reference. If the FM layer is made at the su rface of the irradiated bulk samples, the large peaks at the Fe L_3-, and L_2-absorption edges should have appeared at around 708 eV and 720 eV looking like the case in the samples irradiated with 30 keV Ga ion. As for the Ga ion irradiated thin film samples, uniform magnetization about 400 emu/cc is induced regardless of the depth from the surface. In contrast, the spectra for the sample irradiated with 2.9 and 5.9 MeV He ion beam almost are unchanged to that for the unirradiated sample: i.e., the XMCD peaks at Fe L_3- and L_2-edges corresponding to the presence of the surface magnetization cannot be observed. These experimental evidences mean that the FM state at the bulk surface has not been induced by using high energy He ion beam irradiation. It should be noted here, the results of the XMCD and MCP measurements in the our previous work for the FM in the FeRh bulk and films by the ion beam irradiation suggested the observed FM to be due to the increase in spin magnetic moment. Hence, in the present case, the FM state due to the spin magnetic moment should be considered to be induced at the sub-surface of the samples by the high energy ion beam irradiation.

Considering the experimental evidences indicated in Figs. 1 and 3, the high energy ion beam irradiation like 2.9MeV and 5.9MeV He ion beam did not induced the surface FM state, but the FM regions at the sub-surface of FeRh. Since the calculation TRIM simulation reveals that the large number of lattice defects are introduced in only the part in the ranges of 3–5 μm and 10–12.5 μm from the surface in the FeRh bulk samples for the 2.9 and 5.9MeV ion irradiation, respectively, the FM layer are reasonably speculated to be produced in these regions. In other word, the irradiation induced thin FM layers can be designedly produced in any part of the FeRh bulk by controlling the ion beam energy and ion species. By combining these concepts and the two dimensional magnetic modification technique, the real three dimensional magnetic modification process can be realized. However, we have not been able to find how to characterize this magnetic structure at present.

References
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