§3. Depth Profile of Deuterium in Fe_2O_3 under Low-Energy Deuterium Exposure

Matsunami, N., Sogawa, T., Sakuma, Y. (Nagoya Univ. EcoTopia), Ohno, N. (Nagoya Univ. Engineering), Masuzaki, S., Tokitani, M., Ashikawa, N., Sagara, A., Nishimura, K.

Oxide layers such as Fe_2O_3 will be formed on stainless steel (SUS), one of structure materials widely used for fusion devices [1], during removal process of hydrogen isotopes [2]. Thus, the depth distribution of deuterium (D) and amount of D-retention in the oxide layers are important for designing the devices. We have studied the depth profile of D and D-retention in Fe_2O_3 under low-energy D plasma exposure [3].

Fe_2O_3 layers were prepared by deposition of Fe on SiO_2-glass substrates followed by oxidation in air at 400 to 500 ºC for more than 5 min. X-ray diffraction (XRD) shows that the oxide is α-Fe_2O_3, i.e., hematite (hexagonal corundum structure) and the composition is evaluated to be Fe:O=2:3 with an accuracy of 10% by Rutherford backscattering spectroscopy (RBS) of 1.8 MeV He^+. RBS is also employed to evaluate the film thickness. Nuclear reaction, D(^{3}He,α)P, analysis (NRA) with 1 MeV $^3He^+$ was employed to obtain the depth profile of D. Here, the incident angle and detection angle of α-particles are 20^o and 70^o from the sample surface normal, respectively (NRA angle is 90^o measured from the incident beam direction).

Figure 1 shows the depth profile of D in α-Fe_2O_3. One sees that D's are distributed beyond the depth resolution (43 nm) and the range (30 nm) calculated [4] by considering the fractions of D_3(60%), D_2(38%) and D(2%) [5]. It also appears that more than 90 % of D's are located within the film thickness of 0.1 μm, indicating small diffusivity of D in α-Fe_2O_3 near room temperature. By integrating the D density up to 0.2 μm, the amount of D-retention is obtained to be $45x10^{15}$ cm^{-2} and corrected to be $50x10^{15}$ cm^{-2} by taking $^3He^+$ beam induced desorption (evaluated from measurement of D-retention vs $^3He^+$ beam fluence) into account, in reasonable agreement with the reported value [3]. After the D-exposure, the XRD intensity decreased to 1/3 of that before D-exposure and the lattice parameter increased by 0.4 %. These modifications are not likely due to irradiation effects by low energy D (limited within 30 nm) but incorporation of D into Fe_2O_3 lattice.

In the mixed layers (more than 2 μm) of γ-Fe_2O_3 (maghemite, cubic spinel structure) and α-Fe_2O_3, which were prepared by oxidation of Fe at 400 to 500 ºC, the depth profile of D appears to be similar to that in α-Fe_2O_3, but D-density is larger than that in α-Fe_2O_3 in regions deeper than 0.1μm. D-retention is evaluated to be $73x10^{15}$ cm^{-2}, by integrating the D-density up to 0.5 μm and correcting $^3He^+$ beam induced desorption, the value being in agreement with the reported value ($76x10^{15}$ cm^{-2} [3]). D-retention in the mixed layers is larger than that in α-Fe_2O_3. The difference could be largely due to the difference of the D-distribution mentioned above. D-retention in α-Fe_2O_3 is larger than that in Fe ($12x10^{15}$ cm^{-2}) and SUS316L ($36x10^{15}$ cm^{-2}). Measurements of D distribution in SUS and Fe, dynamic D-retention and thermal desorption of D are under way.

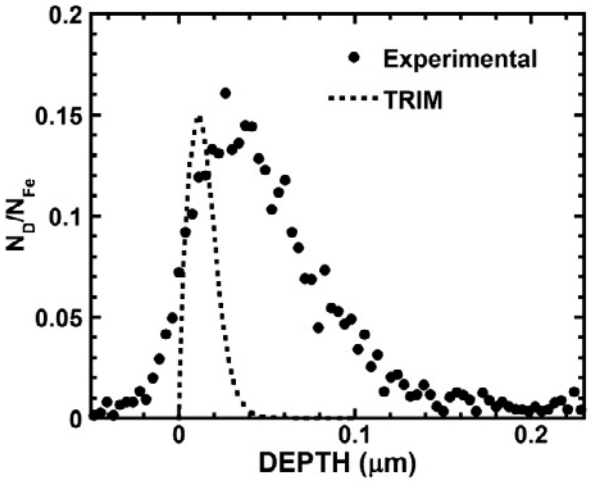

Fig. 1 Depth distribution of D density in α-Fe_2O_3 (thickness of 100 nm) normalized to Fe density exposed to D-plasma (1.5 kV AC glow-discharge in 0.5 Torr D_2 for 30 min) (●). The dotted line indicates the range profile of D calculated using TRIM code [4].

1. C. Anandan, K.S. Rajam, Appl. Surf. Sci. 253 (2007) 6854.
2. R. E. H. Clark, D. H. Reiter, eds. Nuclear Fusion Research, Springer, 2004.
3. N. Matsunami, T. Sogawa, Y. Sakuma, N. Ohno, M. Tokitani, S. Masuzaki, Phys. Scr. T415(2011) 014042, and D-retention in Fe_2O_3 is to be multiplied by 2 for correction in NRA.
4. J.F. Ziegler, J.P. Biersack, U. Littmark, The Stopping and Range of Ions in Solids, Pergamon Press, New York, 1985.
5. H. Sugai, H. Kojima, T. Mori, S. Aoki, T. Okuda, J. Nucl. Mater. 128/129(1984)169.