

## Dynamic Simulation of Erosion and Redeposition Patterns and Impurity Depth Profile of an LHD Divertor Plate

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A three-dimensional dynamic simulation code, which calculates the local transport and redeposition of impurities on a divertor plate and the depth profile of deposited impurities in the plate, is developed. The code simulates the erosion and redeposition patterns of a graphite plate which was used in the third experimental campaign of the large herical device (LHD). The depth profile indicates a prompt, asymmetric redeposition of sputtered Fe atoms.

**Keywords:** Erosion and redeposition patterns, Depth profile, LHD divertor, Dynamic simulation.

The erosion and redeposition patterns on a divertor plate after plasma exposure provide us important information regarding the local transport and redeposition of impurities in the plasma boundary. Since the deposited impurities modify the surface and lead to material mixing, the depth profile in the plate is important as well. In this report, we present a three-dimensional dynamic simulation code for the erosion and redeposition process. The code is applied in order to simulate the erosion and redeposition patterns on a graphite plate which was used in the third experimental campaign of the large herical device (LHD) [1].

Figure 1 shows a schematic view of the divertor geometry. A plasma in the form of a sheet is considered to expose the divertor plate. The electron and ion temperatures,  $T_e$  and  $T_i$ , and the density,  $n_e$ , above the

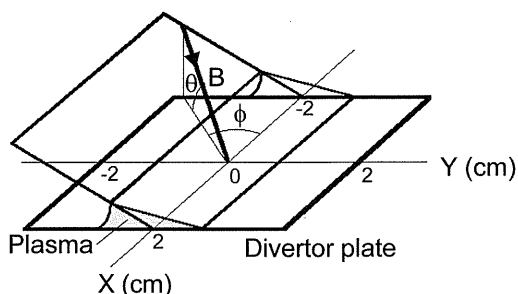


Fig. 1 Schematic view of a divertor geometry.

plate are described by an exponential function. For one of the LHD divertor plates, the values of  $T_e$  and  $n_e$  along the X-axis are typically 24 eV and  $1 \times 10^{12} \text{ cm}^{-3}$  and the decay length along the Y-axis is 0.55 cm for both [1,2];  $T_e = T_i$  is assumed. In the third campaign, the divertor plate was exposed to helium (He) plasmas with a total ion fluence of  $\sim 2 \times 10^{21} \text{ cm}^{-2}$  and to hydrogen (H) plasmas of  $\sim 1.2 \times 10^{21} \text{ cm}^{-2}$ . The ion fluxes decay exponentially along the Y-axis with a decay length of 0.367 cm. The plasma contains impurities of carbon, oxygen, and metals, whose concentrations are estimated to be 2%, 1%, and 0.1% (Fe), respectively [3], and we assume their charge states to be +4. An area of 4 cm $\times$ 4 cm on the plate is divided into 400 (20 $\times$ 20) segments. In each segment, the following dynamic erosion and deposition processes are simulated [4]: sputter erosion, impurity deposition and collisional mixing. Sputtered and reflected impurities undergo successive ionizations by plasma electrons and gyrate in a magnetic field of 1 T, where the angles,  $\theta$  and  $\phi$ , are 27.6 $^\circ$  and 39.6 $^\circ$ , respectively [5]. Some ionized impurities redeposit promptly on the same segment as after they are released, or on the other segment due to friction force in the direction to the plate after migration in the divertor plasma.

Figure 2 shows the typical erosion and redeposition patterns. Owing to deposition of sputtered Fe from the stainless steel wall under glow discharge cleaning [1], the

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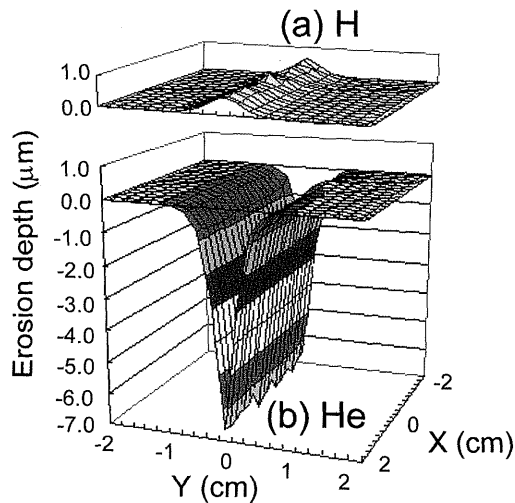


Fig. 2 Erosion and redeposition patterns after exposures of (a) H plasma and (b) He plasma containing impurities of C (2%), O (1%), and Fe (0.1%).

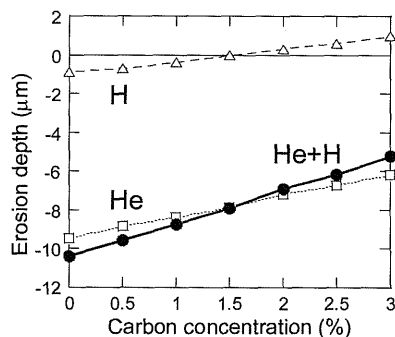


Fig. 3 Erosion depth as a function of carbon concentration of H and He plasmas.

original plate surface is assumed to be covered by a Fe layer at a thickness of  $0.035 \mu\text{m}$ . The thickness was estimated from the observed areal density of  $3 \times 10^{17} \text{ Fe/cm}^2$  [1] and the atomic density of  $8.5 \times 10^{22} \text{ Fe/cm}^3$  in pure element. The He plasma causes net erosion, but the H plasma causes net deposition. The total net erosion depth, therefore, is about  $6 \mu\text{m}$ , which is close to the measured depth [1]. The erosion and deposition are influenced by the concentrations of impurities (Fig. 3) and the temperature of the plasma exposed to the surface. Figure 4 shows Fe depth profiles in the perpendicular direction to the X-axis ( $X = -0.4 \text{ cm}$ ), where the depth is measured below the modified final surface. For the H plasma, C deposition around the X-axis reduces Fe atom density at the top layer of the surface, and Fe atoms are distributed inside the bulk. On the other hand, for the He plasma, Fe atoms are strongly sputtered around the X-

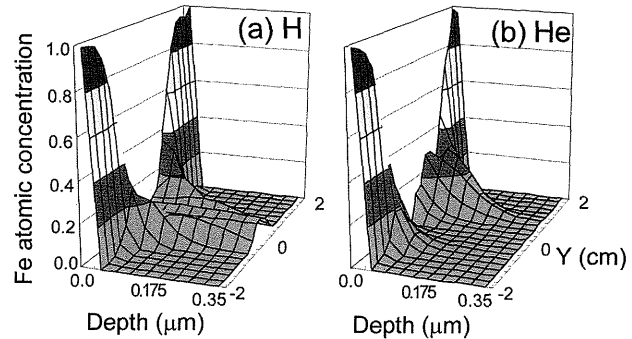


Fig. 4 Depth profiles of Fe atoms after exposures of (a) H plasma and (b) He plasma.

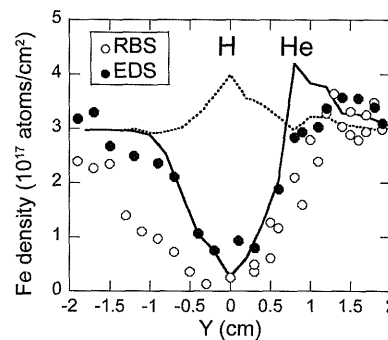


Fig. 5 Calculated and observed Fe distributions on the divertor plate. The observed distributions (RBS, EDS) were quoted from ref. [1].

axis; at the early stage of exposure ( $\sim 10^{20} \text{ cm}^{-2}$ ), the Fe density decreases to  $\sim 30\%$  of the initial value. Furthermore, prompt redeposition of sputtered Fe with  $v \times B$  produces an asymmetric depth profile. The distribution of Fe atoms integrated throughout the entire depth reproduces the observed Fe densities (Fig. 5). This indicates that the distribution is dominated by the He discharge.

In summary, we simulated the erosion and redeposition patterns on a graphite divertor plate used in LHD by means of a 3-D dynamic Monte Carlo code. The depth profile in the plate revealed a prompt, asymmetric redeposition of sputtered Fe atoms.

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