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スパッタリングおよび二次電子放出に対する斜め磁場の運動論的効果
Kinetic effects of inclined magnetic field on sputtering and secondary electron emission

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Impurity in fusion plasma is one of critical subject matters related to energy confinement and engineering design of plasma-facing components. Erosion of the surface dominates the lifetime of divertor plates. Recently, generation and transport of impurities such as carbon, tungsten and beryllium are actively studied in simulations and experiments. The generation of impurities on plasma-facing walls, however, involves atomic processes, plasma physics and kinetics of the charged particle. Therefore particle tracing of impurities and PIC (particle-in-cell) simulation [1,2] of plasma are necessary to understand the characteristics of physical sputtering in realistic magnetic field configurations.

Transport simulation codes [3,4] trace impurity particles generated by sputtering. The generation rate is calculated from particle flux onto the surface and sputtering yield. The flux consists of the impurity particles which return to the surface and background ions in the plasma. The sputtering yield due to the former flux can be obtained from the velocities of traced particles in simulation, however the latter is given only by fluid quantities such as density and temperature. Although a model of velocity distribution of incident particles to calculate the yield has been proposed in [5], magnetic field is not taken into account.

We have developed a particle tracing code to investigate physical sputtering and secondary electron emission. The force acting on a charged particle is calculated from constant magnetic field and electric field given by a PIC code. Incident angle distribution was obtained by solving the orbit of a large number of particles injected far from the wall surface. Figure 1(a) shows mean incident angle as a function of the magnetic field angle from surface normal. Large magnetic field causes large incident angle. This tendency is significant for lighter ion species. The electron has the same tendency but incident angle for normal incident is larger than that of ions. These effects of magnetic field make the sputtering and secondary electron emission (SEE) yields large as shown in Fig. 1(b). The reason is that shallow impact causes larger yield because of effective momentum transport to the target atoms. That suggests importance of modeling of magnetic field effects in impurity transport simulations with realistic surface geometry.

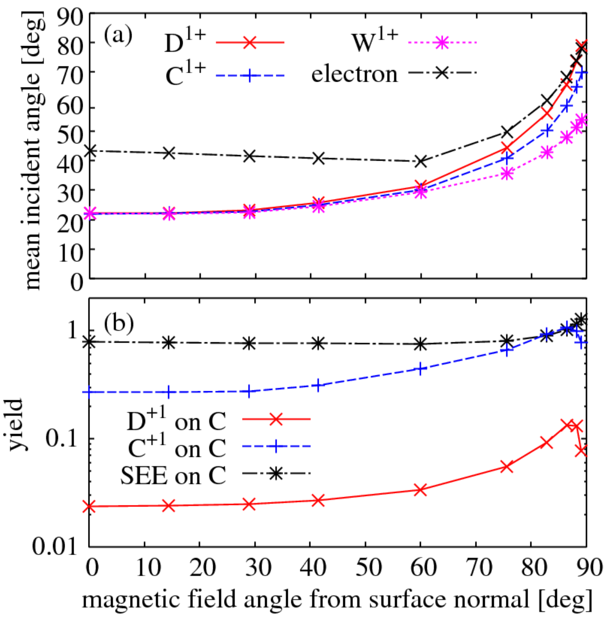

Fig. 1: (a) Incident angle distributions and (b) sputtering and secondary electron emission (SEE) yields obtained for various angles of the uniform magnetic field. The surface material is carbon.

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