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Release of a dust particle in plasma with electron beam component
電子ビーム成分を含むプラズマ中での微粒子の脱離に関する研究

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The release condition of a dust particle from a plasma-facing wall, which is a start point of transport process of dust particles in fusion plasma, is studied theoretically. Analytical model in this study is a spherical and conductor dust particle on a flat and plasma-facing wall. Forces on a dust particle in this model are assumed as electrostatic force, ion friction force and gravitational force. Furthermore, high-energy electron component is important for dust release. Release condition with high-energy electron component is analyzed theoretically. Experiment of dust release with electron beam is carried out.

1. Introduction

In fusion devices, dust particles with different sizes, shapes and compositions are observed in plasma during discharges and they accumulate after discharges on plasma-facing wall (PFW). The elements of dust particles originate in structure materials of divertor plates and first wall. It is supposed that the dust particles are generated by plasma-wall interaction and transported toward the core plasma as impurities. Therefore, release from the PFW and dynamics of dust particles have been studied [1,2]. On the other hand, in the experiment, release of the dust particle from the PFW was observed with electron beam exposure [3,4]. High-energy electron component might have played an important role in dust release.

In this study, simple analytical model, in which a spherical dust particle having a radius much smaller than the Debye length on the flat and PFW, is used and the dust release condition is analyzed theoretically. Forces on a dust particle are analyzed and the plasma condition for the dust particle release is derived. Forces on a dust particle are considered as electrostatic force, ion friction force and gravitational force in this study. But actually, other forces may act on a dust particle, for example, adhesive force. Therefore, the release condition derived in this paper is minimum required condition for release of a dust particle. Moreover, release condition with high-energy electron component is analyzed theoretically and release condition with electron beam component is investigated experimentally.

2. Model

The 1D sheath plasma model is applied. A spherical dust particle is on a flat wall (Fig.1). Wall potential is determined by floating condition. Radius of a dust particle is assumed to be much smaller than the Debye length. Sheath profile is assumed to be unaffected a dust particle. At the sheath entrance, electric potential and electric field are assumed to be zero. The velocity distribution functions of electrons and ions are assumed to be Maxwellian and shifted-Maxwellian distribution, respectively. Electron velocity distribution function is truncated on the high velocity tale of minus, because of wall effect. Ion shift velocity is assumed to be ion sound speed. Both charges of the wall and a dust particle are negative, therefore electrostatic force F_E acts on a dust particle. Additionally, ion friction force F_i due to accelerated ions and gravitational force F_g are considered as forces on the dust particle. The dust particle is released from the wall in a condition of $F_E > F_i + F_g$.

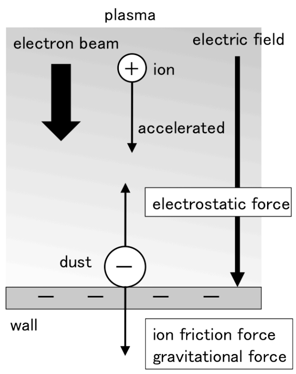

Fig.1 Model

3. Result on single T_e distribution

In a case of a horizontal wall and tungsten dust without electron beam component, dust release condition depends on $\tau_{ie} = T_i/T_e$ and $R_d/n_{se}T_e$ (Fig.2), where T_i and T_e are ion and electron temperature respectively, R_d is dust radius and n_{se} is plasma density at sheath entrance. For dust release, enough small τ_{ie} and $R_d/n_{se}T_e$ are required. At $\tau_{ie} = 0$, dust release condition is expressed in the following equation:

$$\frac{\rho_{d,\mathrm{g/cc}} R_{d,\mu\mathrm{m}}}{n_{se,18} T_{e,\mathrm{eV}}} < 2.80 \qquad (1)$$

Where ρ_d is dust mass density. For example, in the case of $R_d = 1\mu$m, $n_{se} = 10^{18}$ m^{-3} and $\tau_{ie} = 0$, release condition of a tungsten dust is $T_e > 7.1$ eV.

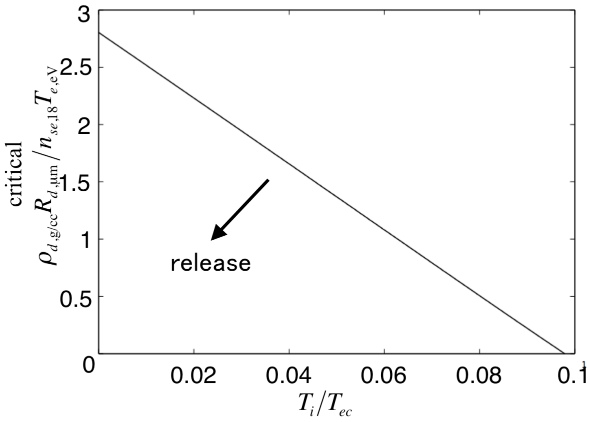

Fig.2 Critical of dust release on single T_e distribution

4. Result on double T_e distribution

In plasma with high-energy electron component, dust particle may be easily released from the wall due to strong electric field. In a case of double electron temperature distribution, dust release conditions are shown Fig.3 and Fig.4, where T_{eh}, n_{eh}, T_{ec} are electron temperature and density of hot electron component and cold electron temperature, respectively. A few percent of high-energy electron components play an effective role for dust release.

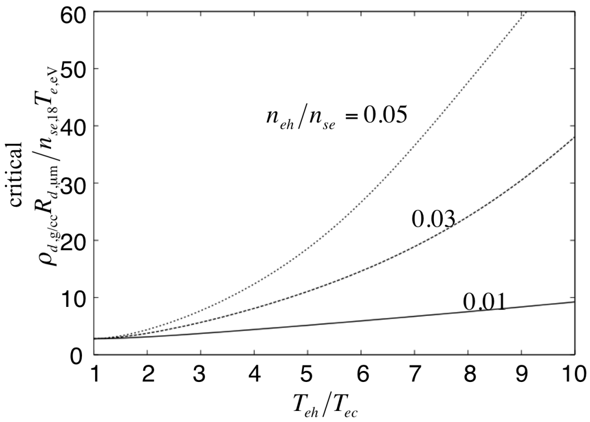

Fig.3 Critical of dust release on double T_e distribution at $T_i = 0$

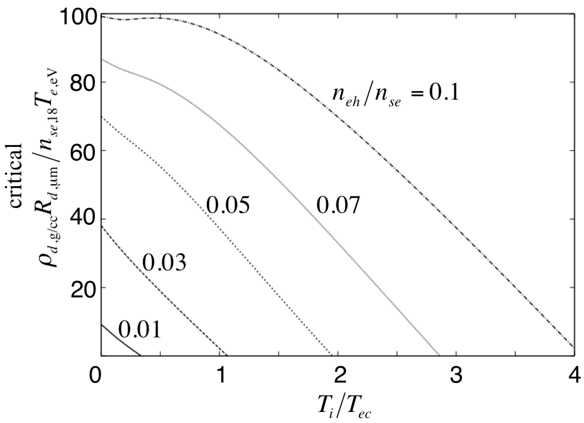

Fig.4 Critical of dust release on double T_e distribution at $T_{eh} / T_{ec} = 10$

Acknowledgments

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