Investigation of Ion Dynamics in Collisionless RF Sheath

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It was invesigated that energy spread of ion energy distribution (IED) which is known as being governed by the dynamics of ion in RF sheath and the magnitude of RF voltage peak. Semi-analytic models was derived from concept of ion response time (τ_i) in previous study. However, the property of ion response time (τ_i) was not clearly understood. In this study, τ_i was investigated with varying RF period (τ_{rf}) in a low pressure Ar plasma. Experiment results revealed that the time scale of ion response time is determined by one of the ion plasma frequency (ω_{pi}) rather than the ion transit time across the sheath (τ_{ion}) in this high-density plasma.

1. Background

The dynamics of ion motion in the collisionless rf sheaths play an important role in the determination of the energy spread of ion energy distribution (IED) with varying RF. Miller et al. proposed the concept of ion response time (τ_i) to RF sheath voltage and assumed that ion thermal motion at sheath boundary determine IED [1]. Sobolewski et al. [2] represented that the ion energy broadness (ΔE_i) is in terms of the sheath voltage oscillation (V_{pp}) and τ_i/τ_{rf} as shown in Equation 1 by using Miller's theory.

$$\Delta E_i = eV_{pp}\left[1+(2\pi)^2\,\tau_i^{\,2}/\tau_{rf}^2\right]^{-1/2} \qquad (1)$$

Previous IED analyses adopted this equation as a function of ion transit imte across the sheath (τ_{ion})/τ_{rf} with a correction factor to explain the experiments or simulation results of ion energy spread [3]. Specifically, the correction factor played important role in the analyses. In this study, we focused on what physics governs the correction factor, consequently defining the ion response time τ_i with RF voltage oscillation. Experimental data taken in the low pressure Ar plasma with various RFs were compared to Equation (1) with the time scale of τ_{ion} and time scaled of $1/\omega_{pi}$.

2. Experimental setup

Experiment were performed in an argon VHF-CCP at 20 mTorr which has the ratio of maximum sheath size to ion mean free path ~ 2. Various ranges of RF (from $\tau_i/\tau_{rf}\sim 0.05$ to $\tau_i/\tau_{rf}\sim 10$) were applied to bottom electrode to enhance the incident ion energy with very high frequency (VHF, $\tau_i/\tau_{rf}\sim 10$) which was applied on the top electrode (showerhead) to sustain plasma. One RF bias power was applied to bottom electrode alone. A commercial retarding field analyser (Impedans, Vertex V4.0.10) was employed to measure IED. Plasma density, electron temperature and plasma potential were measured by using RF compensated Langmuir probe.

3. Results and Discussion

Experimental results of ΔE_i to V_{pp} are summarized in Figure 1. It is compared with models under assumptions that ion response time is ion transit time (indicated by solid and dotted lines) or one of ion plasma frequency (indicated by dashed line). The dashed line is agreed well with the experiments results, implying that the ion energy arriving at surfaces is governed by the ion thermal motion at the sheath boundary. Consequently, it determines the initial condition of ion acceleration.

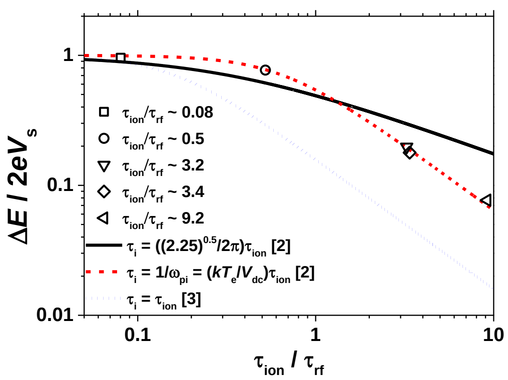

Figure 1. The ratio of ion energy broadness to sheath voltage magnitude as a function of τ_{ion}/τ_{rf} (symbols) for comparison between models (lines).

4. References

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