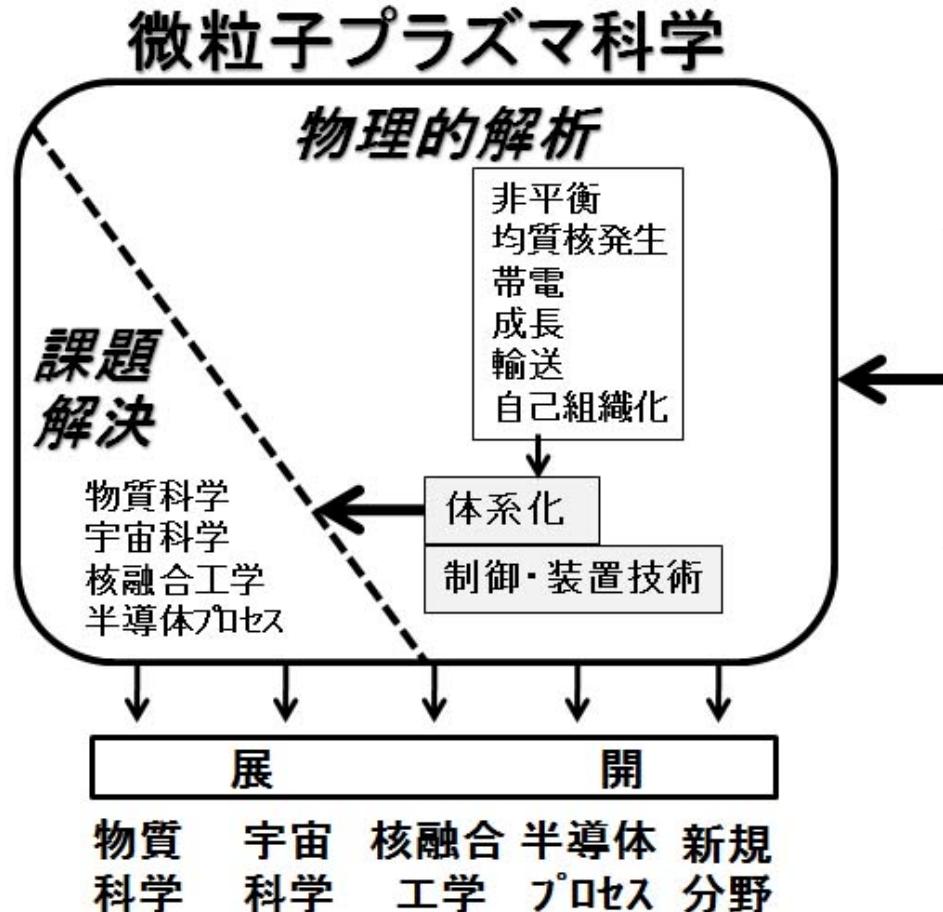
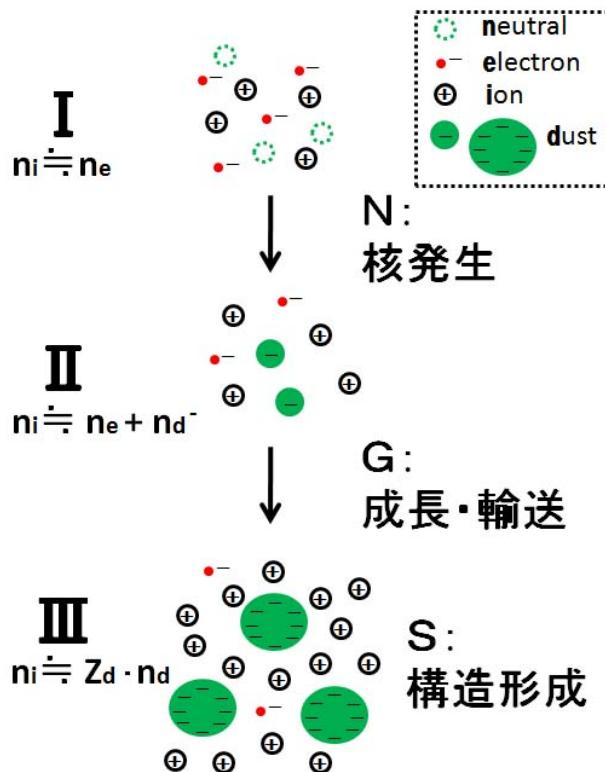


実験室プラズマにおける 微粒子のクーロン結晶化と 挙動

京都工芸繊維大学大学院 工芸科学研究科

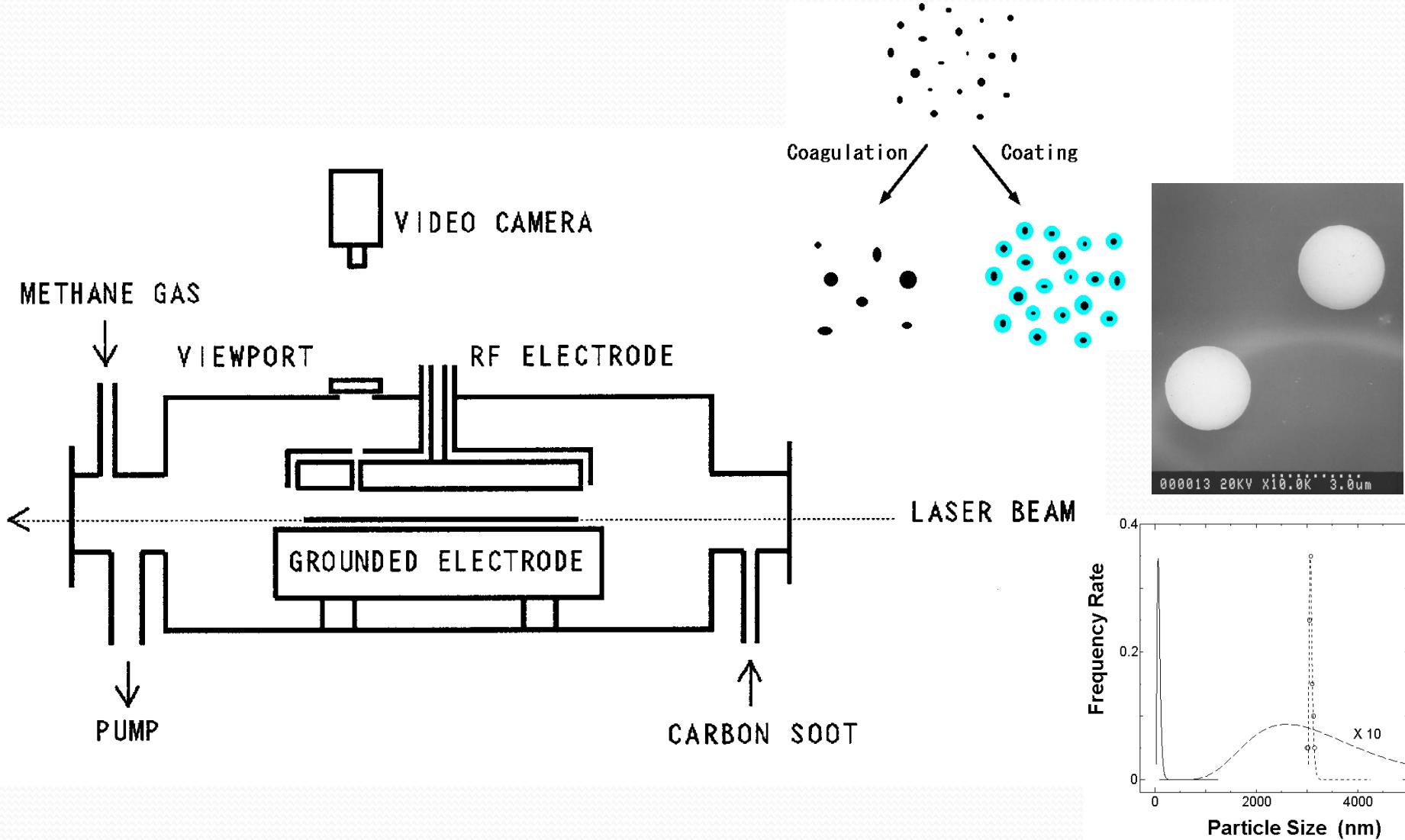
林 康明

微粒子プラズマ科学の体系化と展開

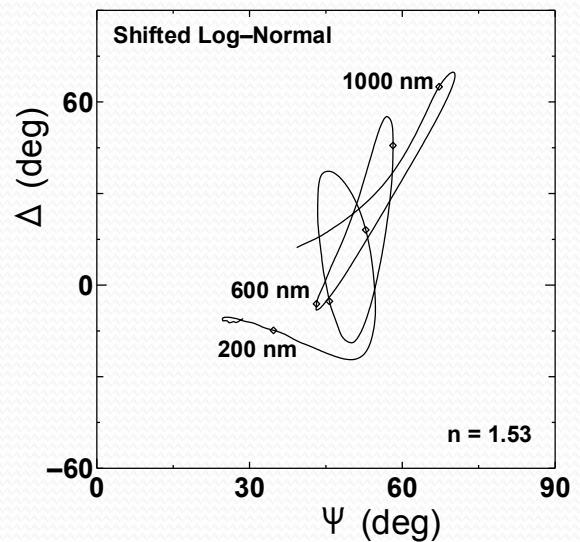
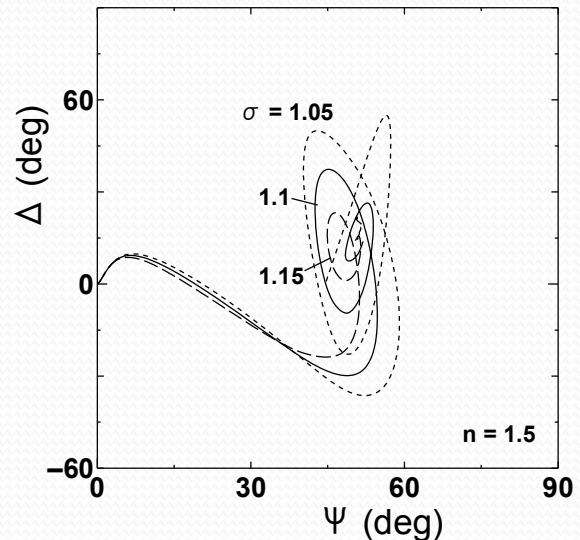
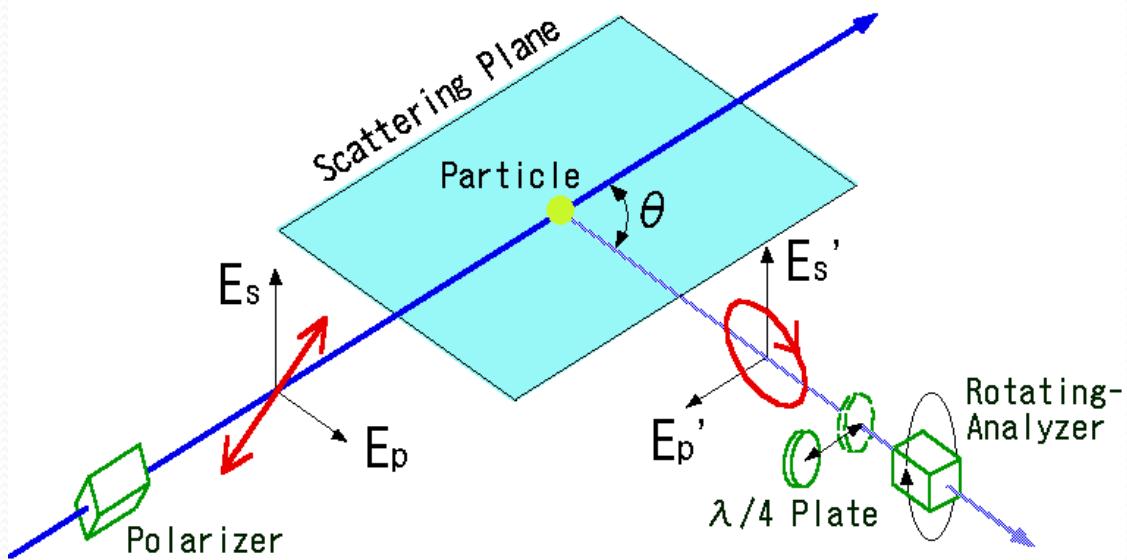


- 1. 成長微粒子によるクーロン結晶化**
- 2. マグネットロンプラズマ中の微粒子の挙動**
- 3. 非球形微粒子の挙動**

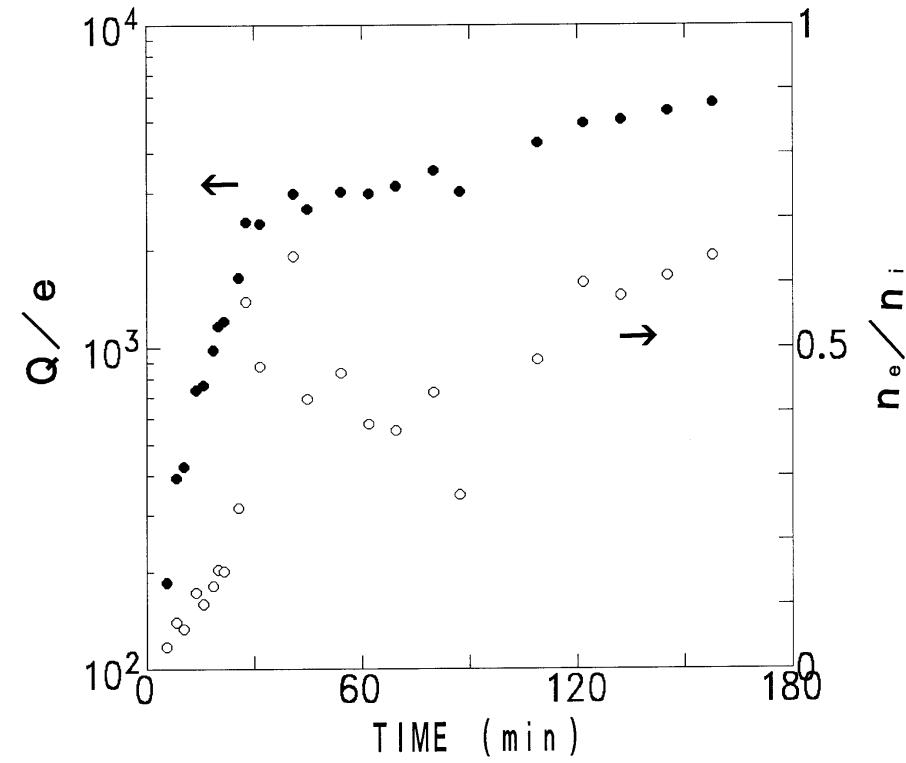
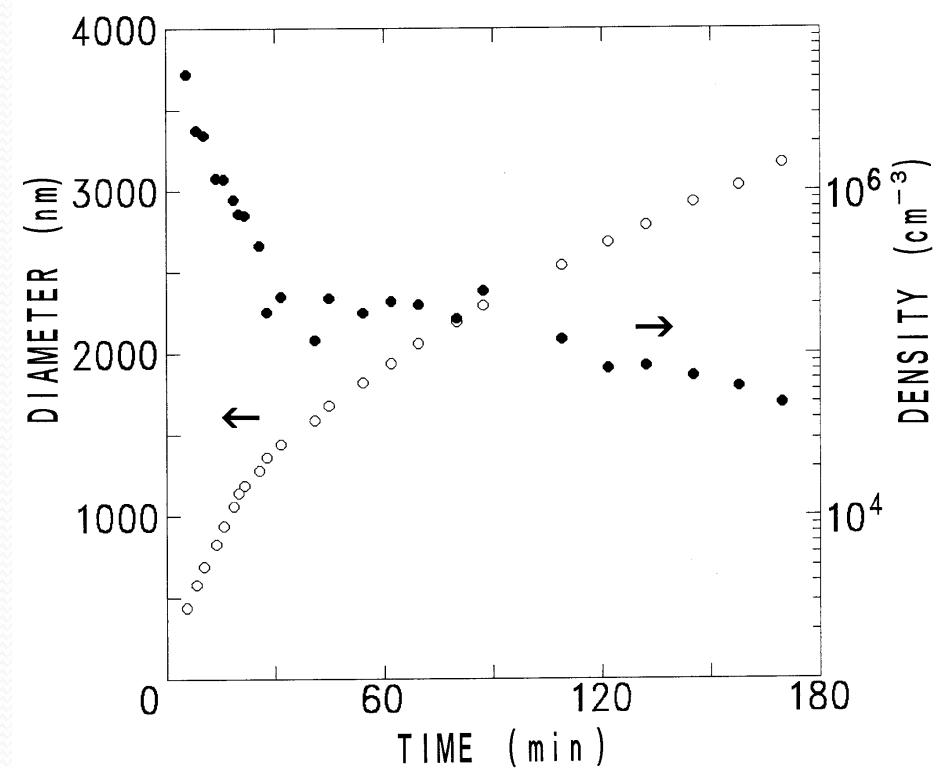
[成長] 微粒子プラズマ実験装置



ミー散乱エリプソメトリ



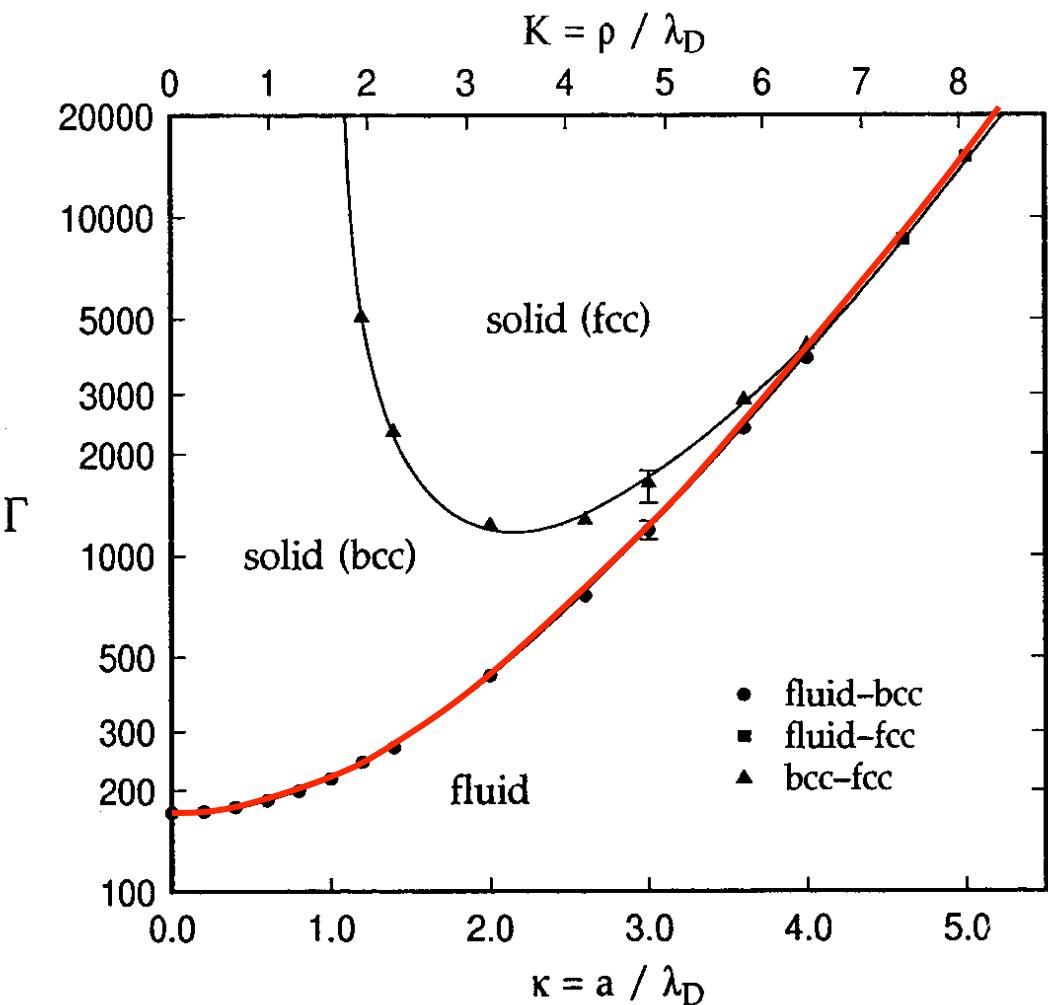
成長微粒子の粒径と負帯電量



$$1 + \frac{1}{2\pi\epsilon_0 d} \frac{eQ}{k_B T_i} = \left(\frac{m_i T_e}{m_e T_i} \right)^{\frac{1}{2}} \frac{n_e}{n_i} \exp \left(- \frac{1}{2\pi\epsilon_0 d} \frac{eQ}{k_B T_e} \right)$$

$$n_e + \frac{Q}{e} N = n_i$$

Γ - κ 相図



$$\Gamma = \frac{Q^2 / (4 \pi \epsilon_0 a)}{k_B T}$$

$$\Gamma^* = \Gamma \cdot e^{-\kappa}$$

$$\kappa = a / \lambda_D$$

a :平均微粒子間半径

λ_D :デバイ長

成長に伴う 微粒子配列 の変化

3D Crystal

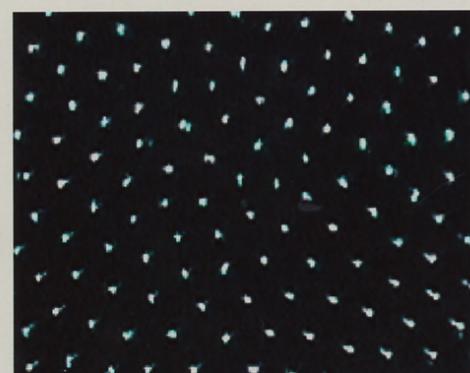
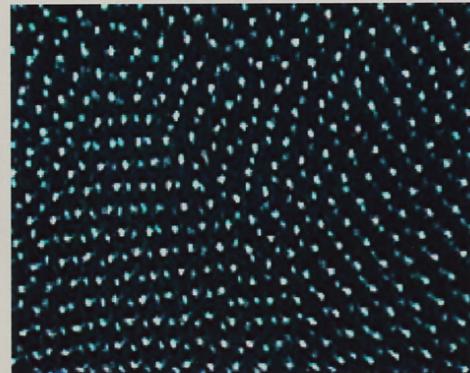
30
min

45
min

80
min

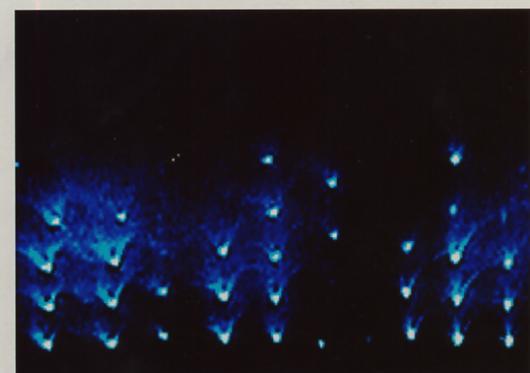
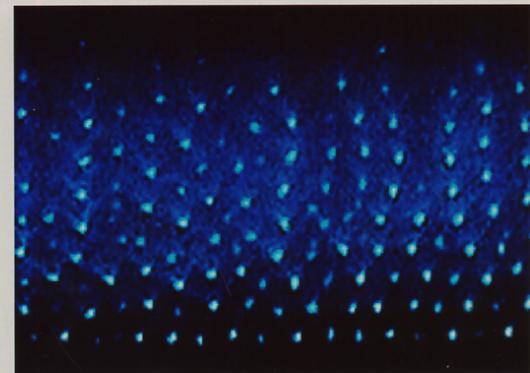
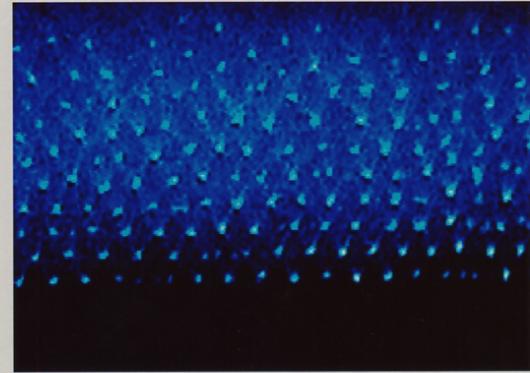
2D Crystal

TOP VIEWS



1 mm

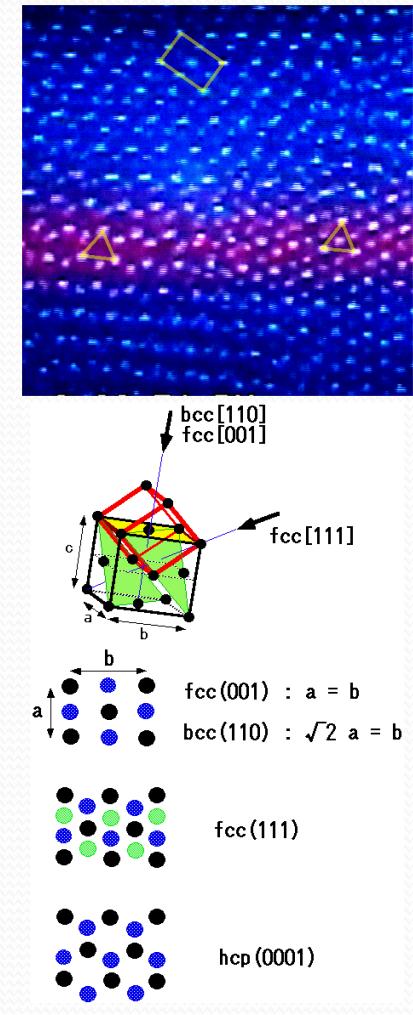
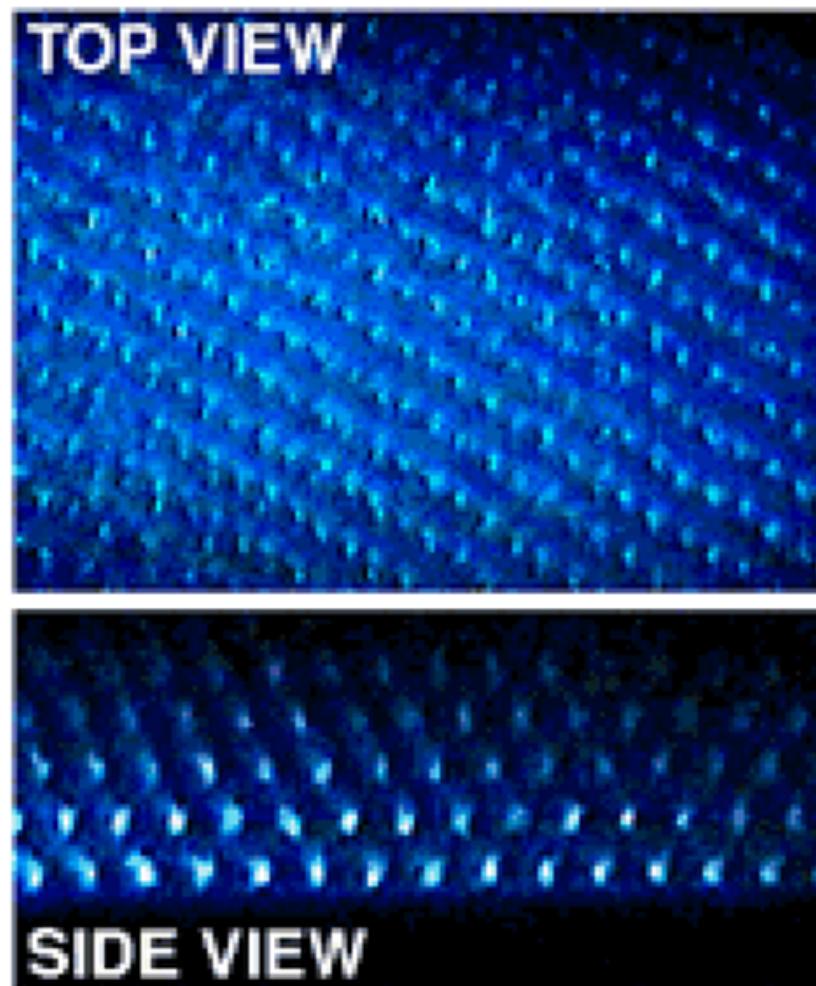
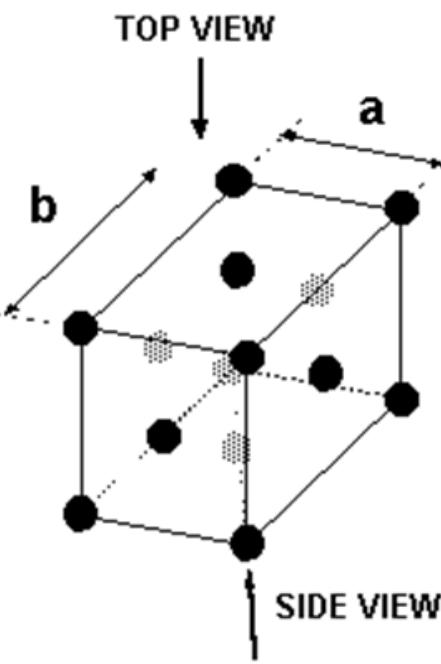
SIDE VIEWS



1 mm

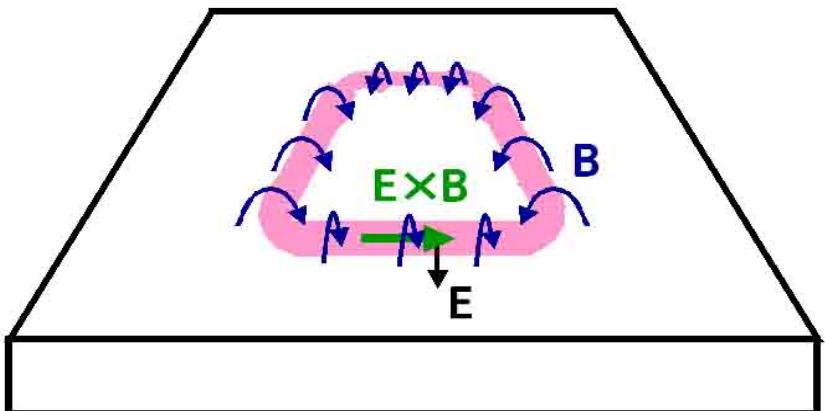
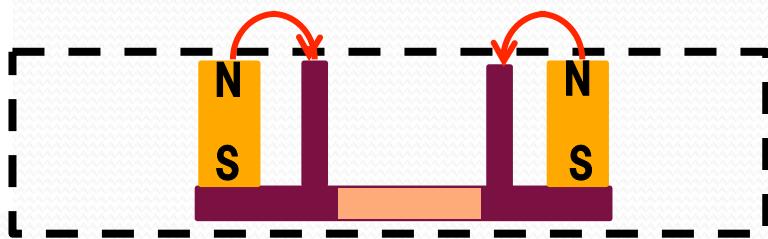
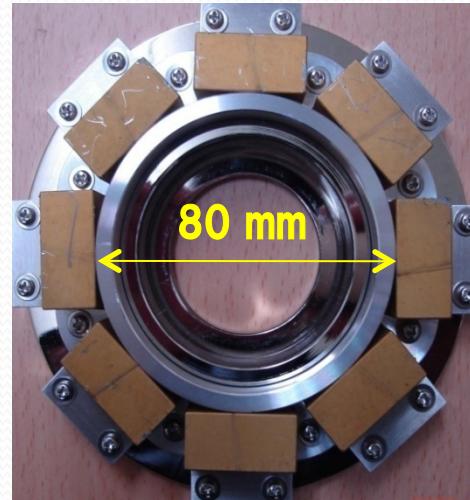
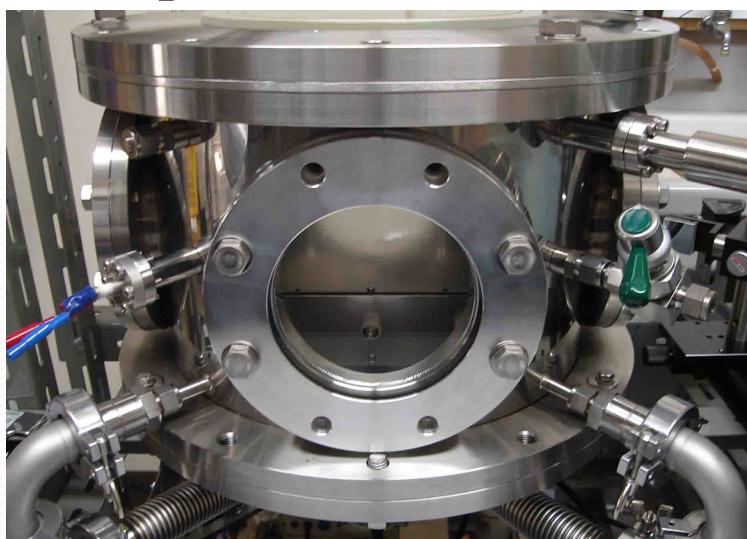
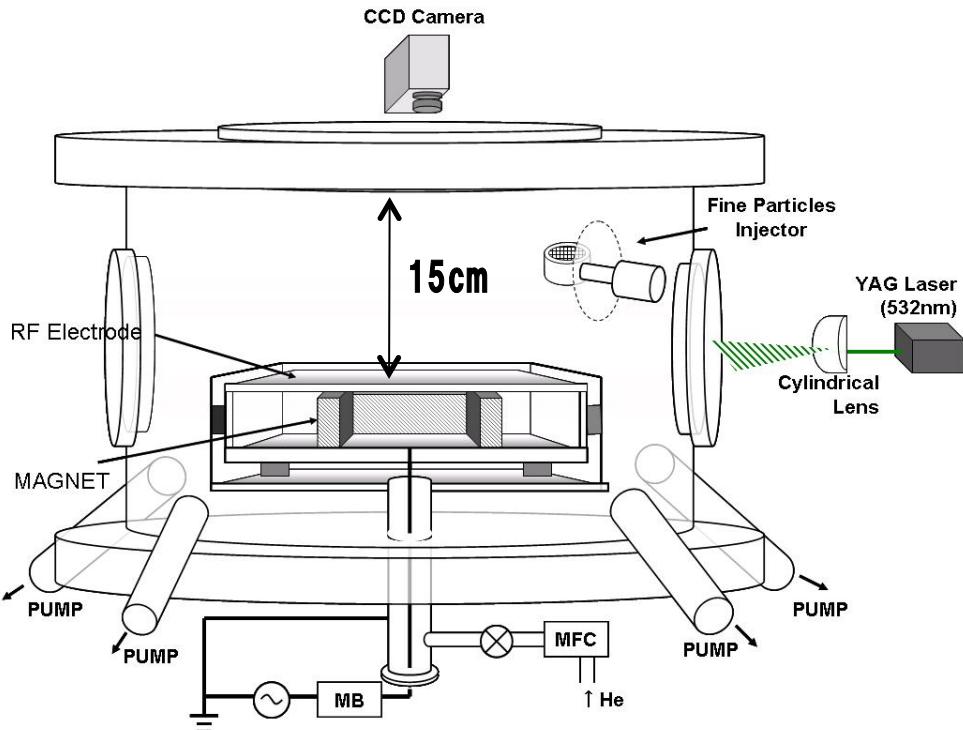
3次元クーロン結晶

成長カーボン微粒子（直径 $1.4\text{ }\mu\text{m}$ ）

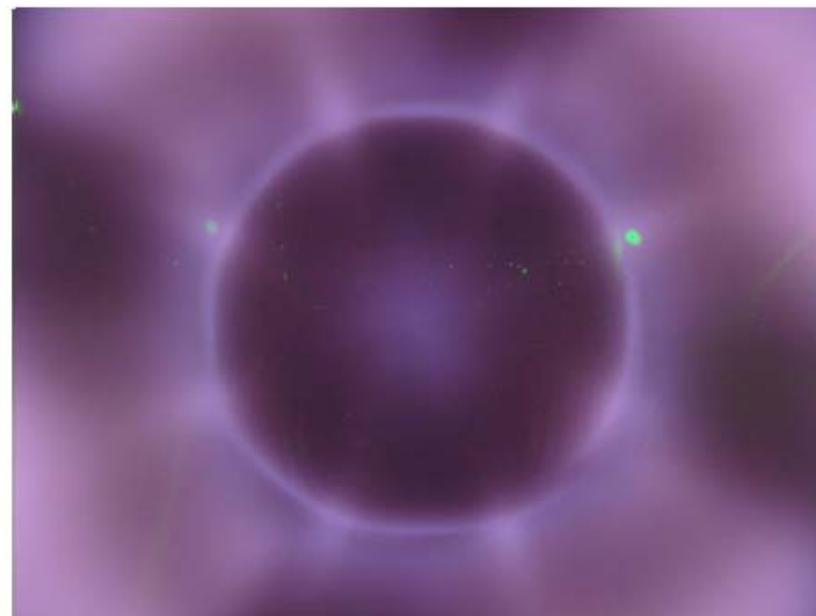
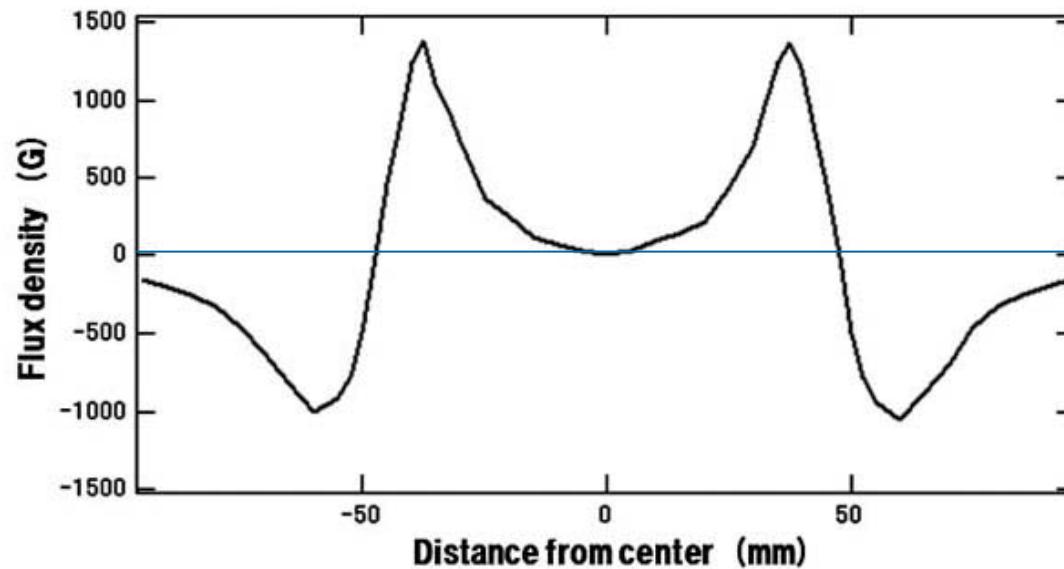


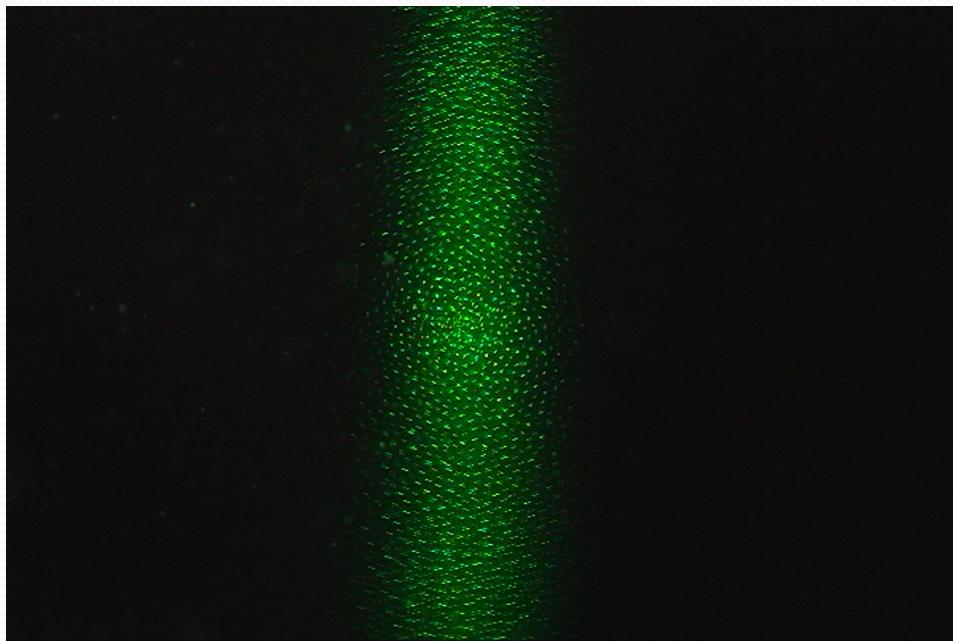


マグネットロンプラズマ中における微粒子の挙動

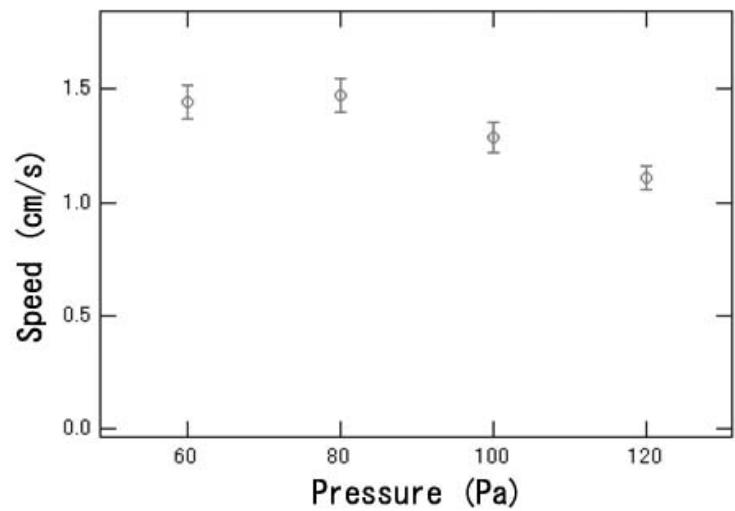
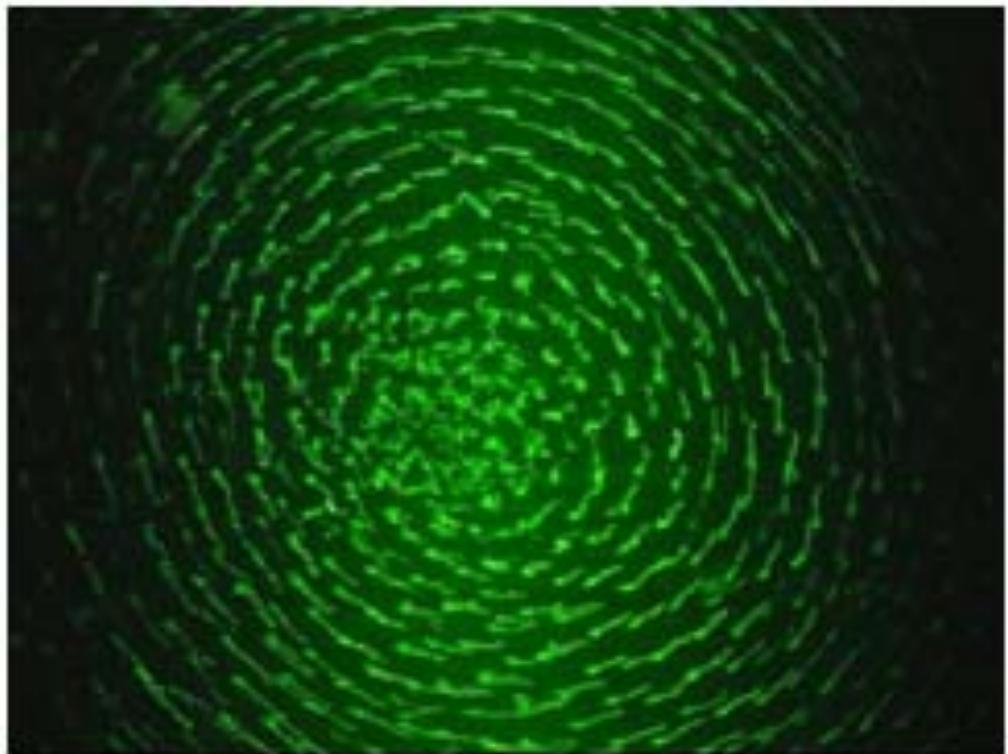


磁場とプラズマの分布





6.5 μm 微粒子の挙動



Dynamic Equation for a Fine Particle

$$M \frac{dV_D}{dt} = f_{ion} - f_{gas}$$

$$f_{ion} = n_i v_s m_i V_d \sum_i \quad \text{Ion Drag Force}$$

$$f_{gas} = n_o v_o m_o V_D S_D \quad \text{Gas Drag Force}$$

At steady state

$$f_{ion} = f_{gas}$$

∴

$$\frac{V_D}{V_d} = \frac{n_i}{n_o} \frac{m_i}{m_o} \frac{v_s}{v_o} \frac{\sum_i}{S_D}$$

Calculation of V_D/V_d

$$n_i = 1.1 \times 10^9 [cm^{-3}], \quad n_o = 2.6 \times 10^{16} [cm^{-3}] \leftarrow p = 100 [Pa]$$

$$\therefore \frac{n_i}{n_o} = 4.2 \times 10^{-8}$$

$$m_i \cong m_o \quad \therefore \frac{m_i}{m_o} \cong 1$$

$$\frac{v_s}{v_o} = \sqrt{\frac{V_d^2 + V_{ith}^2}{V_{oth}^2}} \cong 4.6 \quad \text{for} \quad T_i \cong 0.1 [eV], T_0 \cong 0.025 [eV]$$

$$\Sigma_i \cong \pi \lambda_D^2 \quad \lambda_D \cong 74 [\mu m]$$

$$S_D \cong \pi \left(\frac{r_D}{2} \right)^2 \quad r_D = 6.5 [\mu m]$$

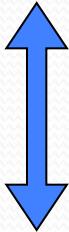
$$\begin{aligned} \therefore \frac{V_D}{V_d} &= \frac{n_i}{n_o} \frac{m_i}{m_o} \frac{v_s}{v_o} \frac{\Sigma_i}{S_D} \\ &= (4.2 \times 10^{-8}) \cdot 1 \cdot 4.6 \cdot \frac{74^2}{\left(\frac{6.5}{2}\right)^2} \\ &= 9.3 \times 10^{-5} \end{aligned}$$

Comparison between Calculated and Measured Values

Calculated

$$V_D = 9.3 \times 10^{-5} V_d$$

$$= 4.2 \times 10^{-1} \quad [\text{m/s}]$$



Measured

$$V_D = 1.3 \times 10^{-2} \quad [\text{m/s}]$$

Hall Parameters of Electron and Ion

Electron Hall Parameter

$$h_e = \frac{f_{ce}}{\nu_{en}} = \frac{eB}{\nu_e n_o \sigma_e} \cdot \frac{1}{2\pi}$$
$$= \underline{\underline{1.4}}$$

$$n_o \leftarrow p = 100 [Pa]$$

$$\nu_e \leftarrow (T_e \cong 5 eV)$$

$$\sigma_e \rightarrow 4 \times 10^{-16} cm^2$$

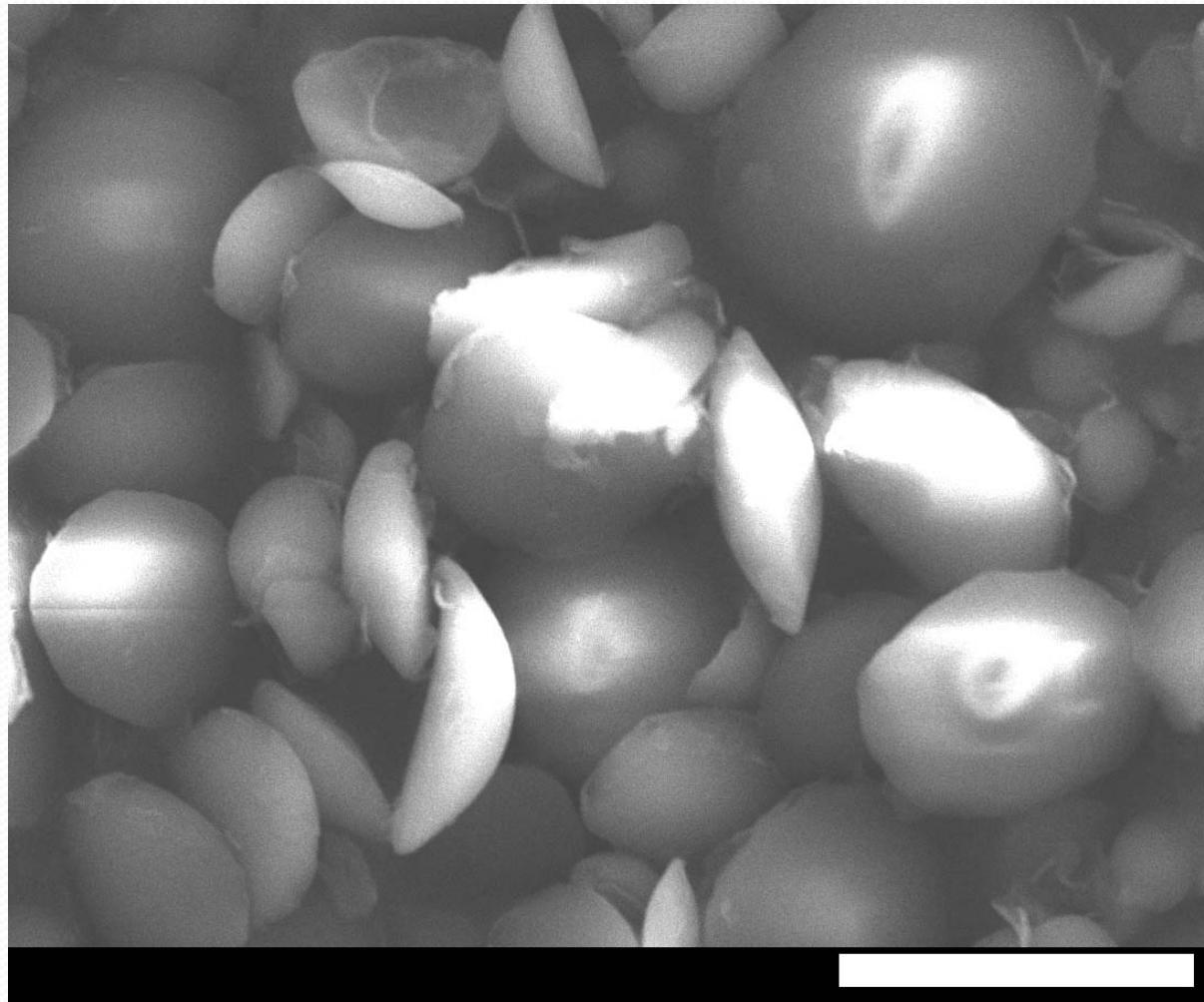
Ion Hall Parameter

$$h_i = \frac{f_{ci}}{\nu_{in}} = \frac{eB}{\nu_i n_o \sigma_i} \cdot \frac{1}{2\pi}$$
$$= \underline{\underline{0.02}}$$

$$m_i = 4 \times 1836 m_e$$

$$\nu_i \leftarrow (T_i \cong 0.1 eV)$$

非球形微粒子の挙動



10 μm

