2-D PIC Simulation on Space-charge Limited Emission Current from Plasma-facing Components

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Abstract

Thermoelectron emissions from plasma facing components have been studied using 2-D particle in cell simulation code (**Berkeley code**). The precise evaluation of the thermoelectron emission current in plasmas is essential to study the plasma heat flow to the material surface, for example, the formation of the hot spot. It is found that the space-charge limited current strongly depends on whether the periphery of the hot spot is insulator or conductor which is due to the modification of potential profiles in front of the plasma-facing components.

Introduction

Plasma heat flow to material surfaces depends on the characteristics of the plasma sheath located between the plasma and the material surface. In recent year, it has become one of the most critical issues for divertor physics in magnetically confined fusion devices to control impurities emitted from the divertor plate. The formation of hot spots, related to a strong thermoelectron emission from the divertor plate, lead to an enhancement of impurities as well as material erosion. The emission current is thought to be regulated by space-charge effect in the sheath. In order to understand characteristics of the electron-emissive divertor target plate associated with the formation of hot spots, it is necessary to study the space-charge effect on thermoelectron emission in plasmas.

In this presentation, we performed 2-D PIC simulation by using **Berkeley code** to evaluate space-charge limited current in plasmas. We will discuss the effect of modification of potential profile in front of the target plate, depending on the conductivity of the material surface.

Introduction(2)

The space-charge limited current in vacuum is described by Child-Langmuir expression

$$j_{CL} = \frac{4\varepsilon_0}{9d^2}\left(\frac{2e}{m_e}\right)^{1/2}\phi^{3/2}$$

d:distance between two electrode
ϕ :voltage between two electrode

The modified Child-Langmuir expression in plasma is proposed by putting d=k λ_d **and** $\phi \rightarrow \phi_s$

$$j_{CL}^{M} = \frac{4n_{se}e}{9k^2}\left(\frac{2T_e}{m_e}\right)^{1/2}\Phi_s^{3/2}$$

ϕ_s:sheath potential
λ_d:Debye length

$$\lambda_d = \left(\frac{\varepsilon_0 T_e}{ne^2}\right)$$

$\Phi_s \equiv \frac{e\phi_s}{T_e}$ normalized sheath voltage

n_{se}:plasma density at the sheath edge

Introduction(3)

The analytical expression giving the space-charge limited current for any sheath voltage

$$j_s^A = \frac{(-\pi \Phi_s)^{1/2} g}{1+g} n_{se} e \left(\frac{2T_e}{\pi m_e} \right)^{1/2},$$

where

$$g = \left[-\beta_1 + (\beta_1^2 - 4\beta_0\beta_2)^{1/2} \right] / (2\beta_2)$$

$$\beta_0 = -4\Phi_s^2 - 2\Phi_s(e^{\Phi_s} - 1)(e^{\Phi_s} - 3)$$

$$\beta_1 = 4(1 - 2e^{\Phi_s})\Phi_s^2 + 8(e^{\Phi_s} - 1)\Phi_s - (e^{\Phi_s} - 1)^2$$

$$\beta_2 = 4\Phi_s^2 - 8\Phi_s^3$$

This expression agrees well with 1-D PIC simulation

Thermoelectron emission currents is given by the

Richardoson-Dushman's temperature limited formula

$$j_{thT} = AT^2 \exp\{-e\phi_W / (kT)\}$$

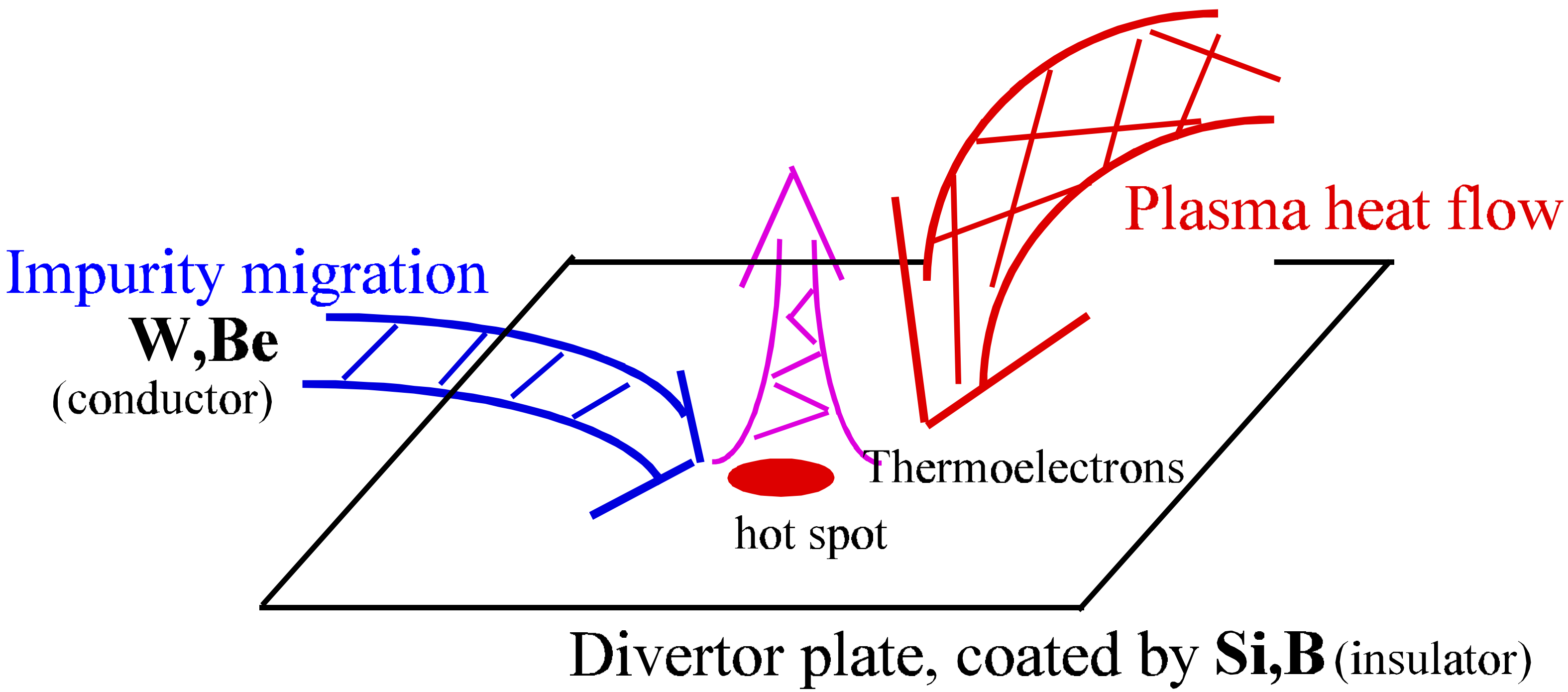
ϕ_w: work function of the target material, chosen 2.7 eV

A: Dushman's constant, chosen $2.9 \times 10^5 Am^{-2}K^{-2}$

↓

LaB6 is assumed as the target plate

Why 2-D PIC simulation is needed?

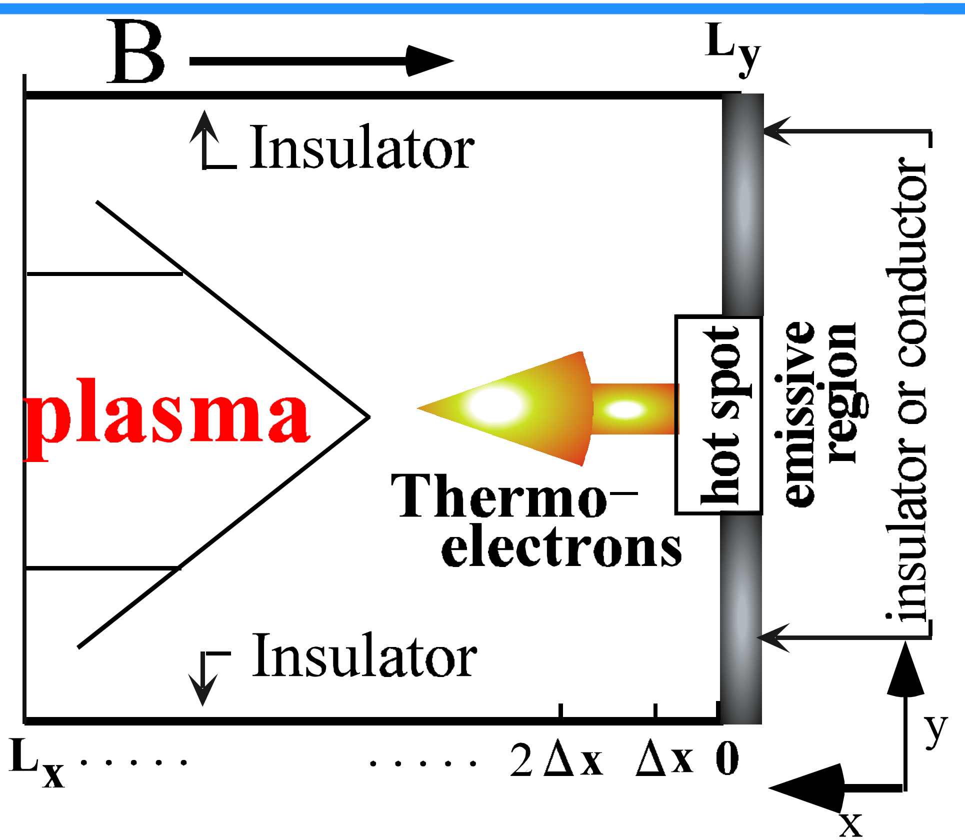


The sheath potential profile could be complicated due to various wall condition

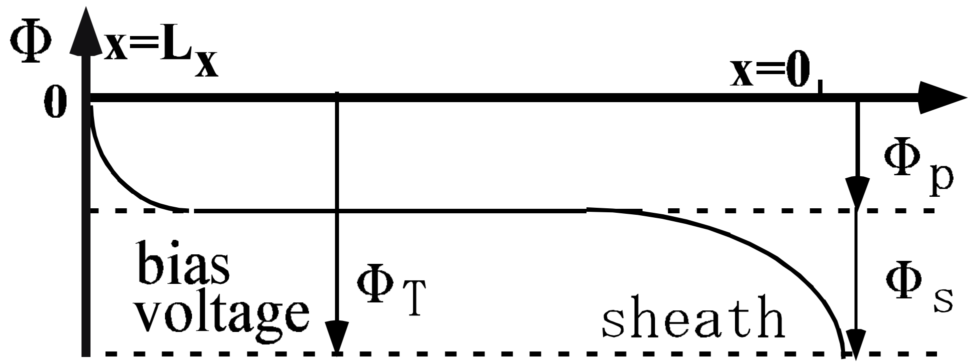
→ conductor and insulator

In order to evaluate space-charge limited current precisely, we need to consider 2-D sheath potential profile

Simulation model



Schematic diagram of simulation



Potential profile along x

plasma parameter

T_e=10 eV, T_i=1 eV
$n_e=n_i=10^{19}$ m^{-3}

Time step

$$\Delta t = \frac{1}{40 f_{pe}}$$

Mass ratio

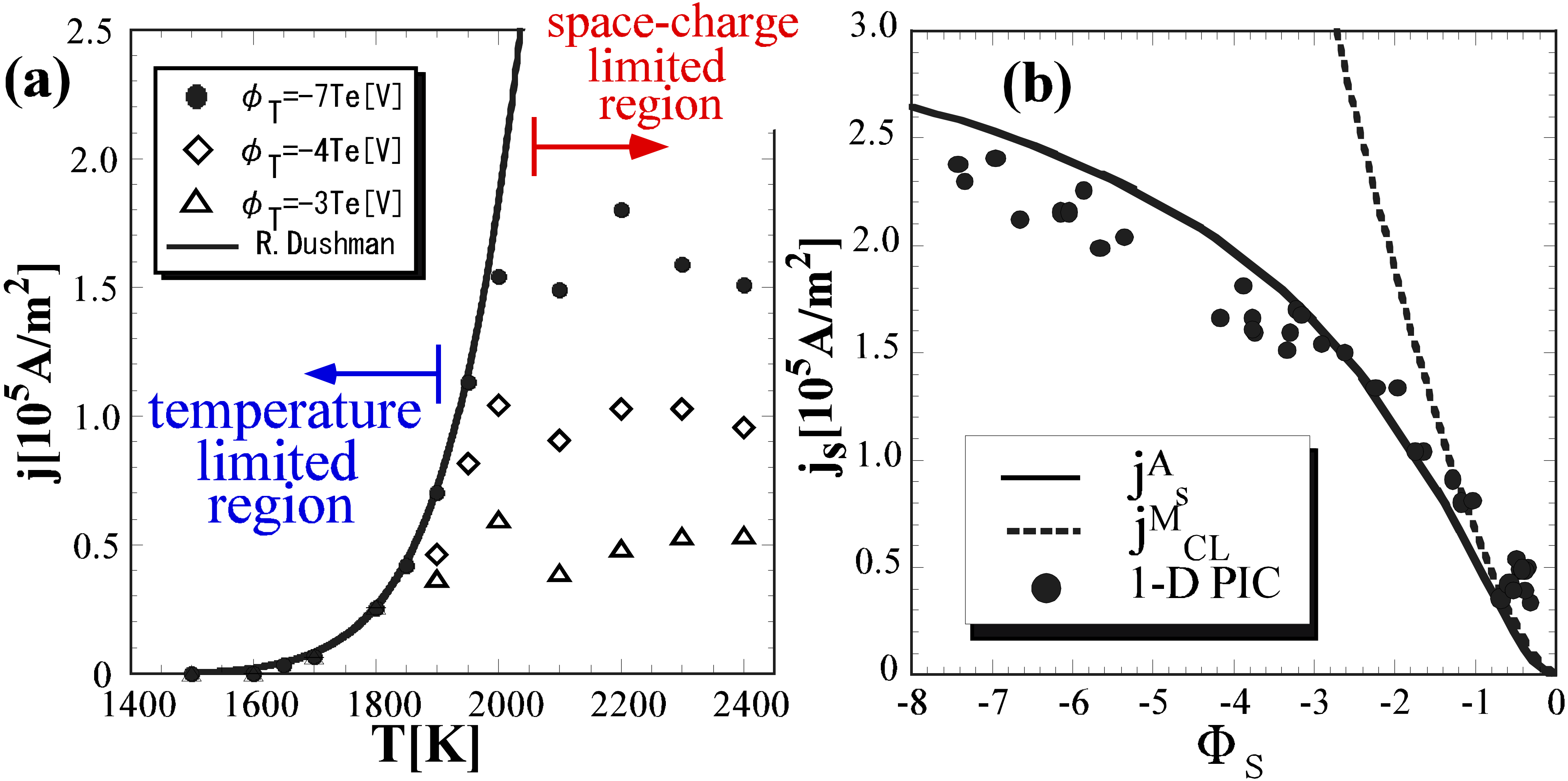
$$\frac{m_i}{m_e} = 4 \times 1840$$

helium plasma is assumed

$$\Phi_s = \Phi_T - \Phi_p$$

sheath potential, target potential, plasma potential

1-D simulation results



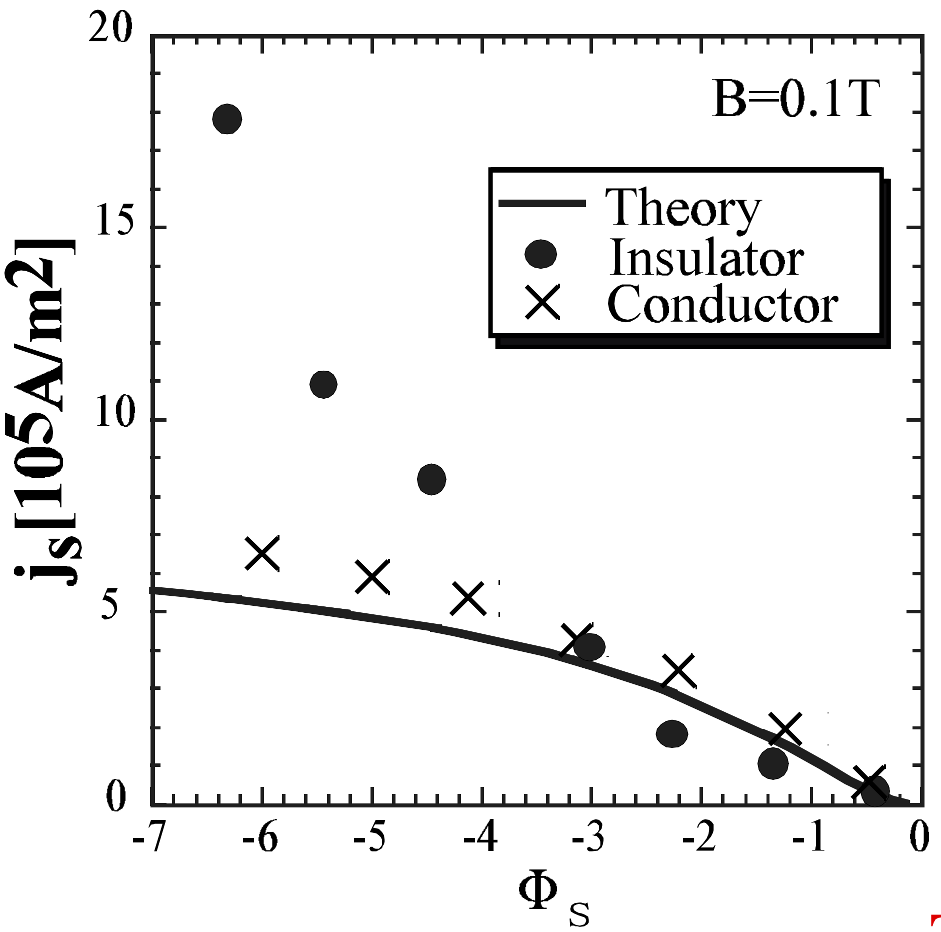
(a):Dependence of thermoelectron current on the temperature of the emissive region T.

(b):Dependence of space charge limited current on the normalized sheath potential Φ_S.

$$\Phi_s \equiv \frac{e\phi_s}{T_e}$$

2-D simulation results (1)

Comparing with the material surface around the emissive region



Dependence os space charge limited current, j_S on Φ_S

Conductor surface

Good agreement with theoretical one

Insulator surface

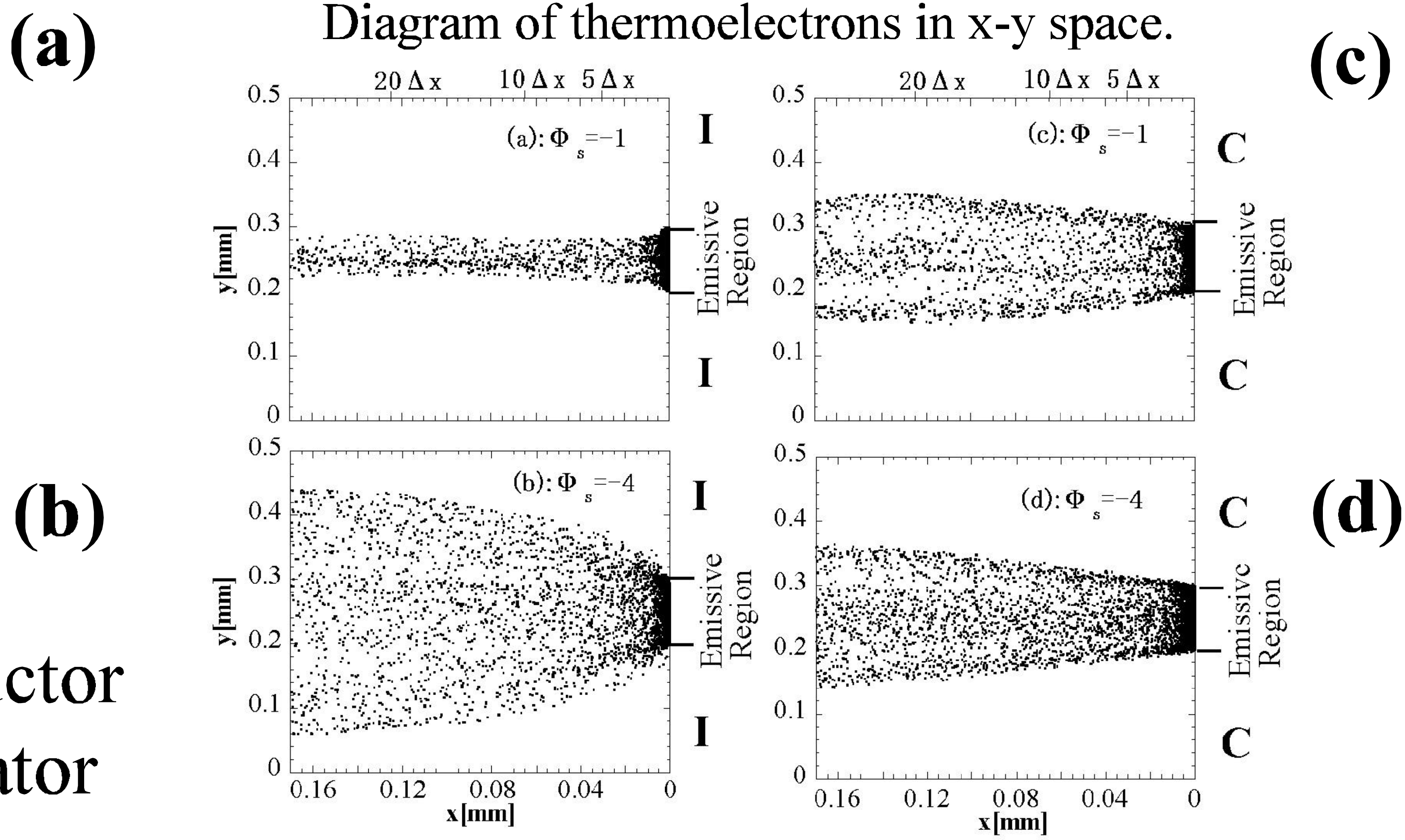
$|\Phi_S|<3$: j_S is suppressed to be compared with the theoretical one.

$|\Phi_S|>4$: j_S becomes larger than that one.

That is due to potential profile in front of emissive region

2-D simulation results (2)

Diagram of thermoelectrons in x-y space.



C :conductor

I :insulator

Orbits of Thermoelectrons are modified due to electric field

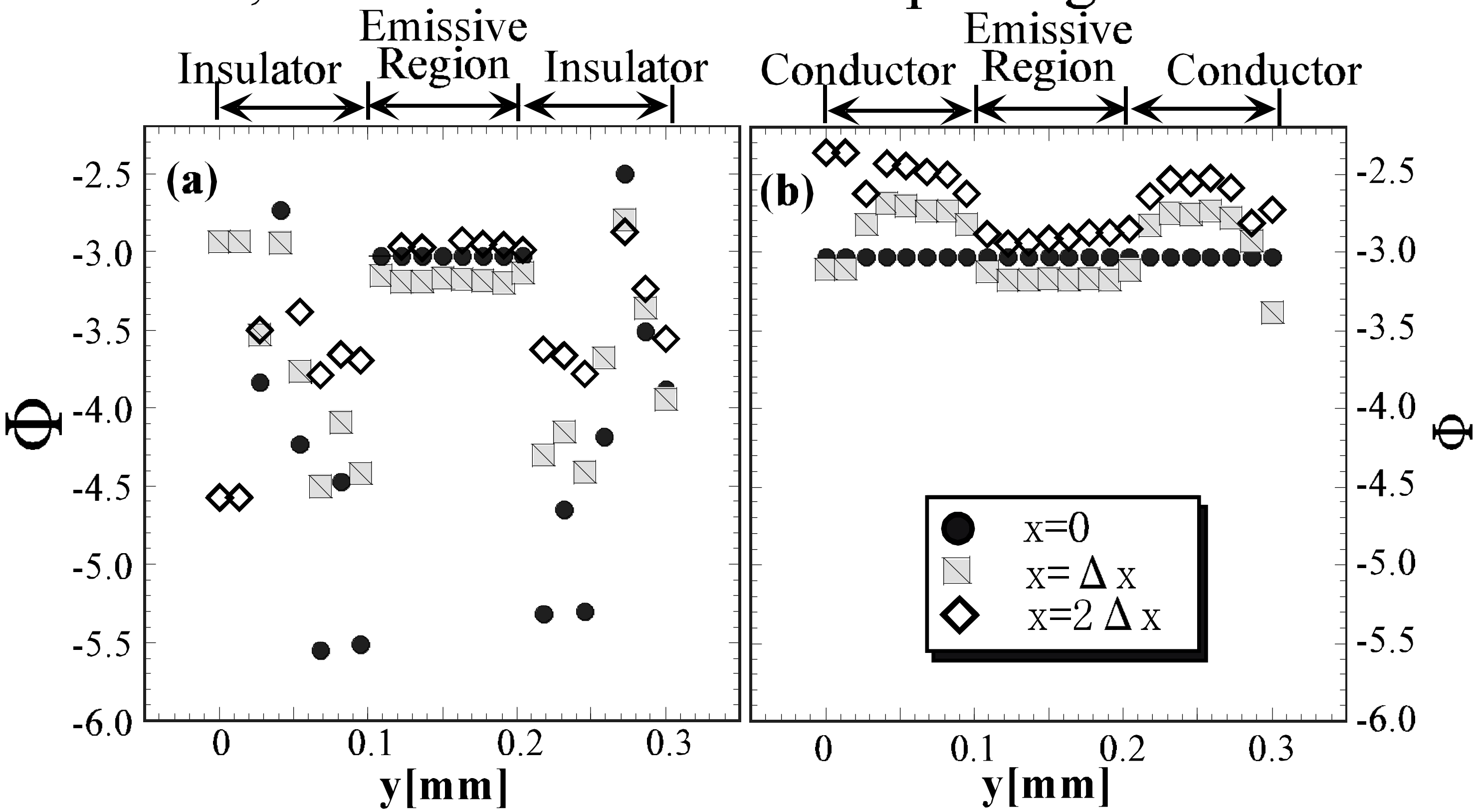
This explains that characteristic shown in Fig. is obtained

2-D simulation results (3)

Normalized potential profile Φ

at x=0, Δx and 2Δx : Δx is spatial grid size

B=0.1 T

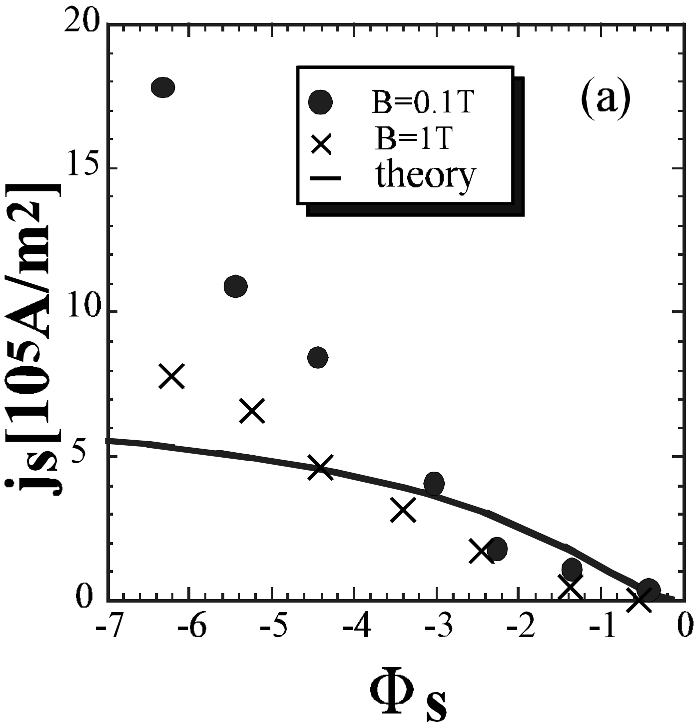


Material surface around the emissive region is (a):insulator and (b):conductor

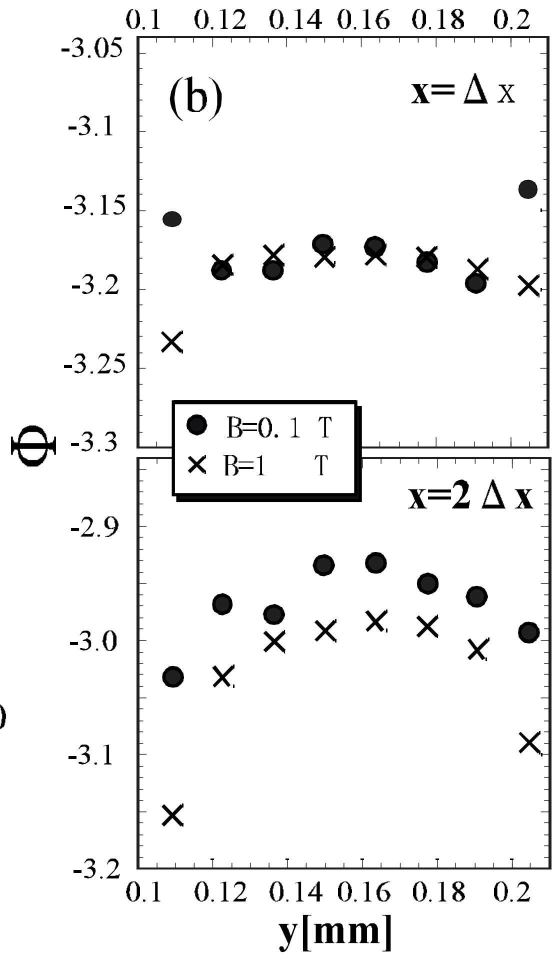
The virtual cathode is formed at x=Δx

2-D simulation results (4)

Dependence of space charge limited current on magnetic field



(a):Dependence of j_S on sheath potential Φ_S at B=0.1 T and 1 T



(b):Potential profile in front of emissive region

These indicate,

Strong magnetic field suppresses emission current

due to small Larmor radius and restraint orbital deflection of Thermoelectrons

Conclusion

The space-charge effect for the thermoelectron emission currents in plasmas has been studied via 1-D and 2-D PIC simulation

- 1-D PIC simulation is performed in order to evaluate the theoretical expression describing the space-charge limited current.

  → Theoretical value agrees well with 1-D PIC simulation results.

- 2-D PIC simulation is performed in order to study the emission current from hot spot by taking account of 2-D sheath potential profile.

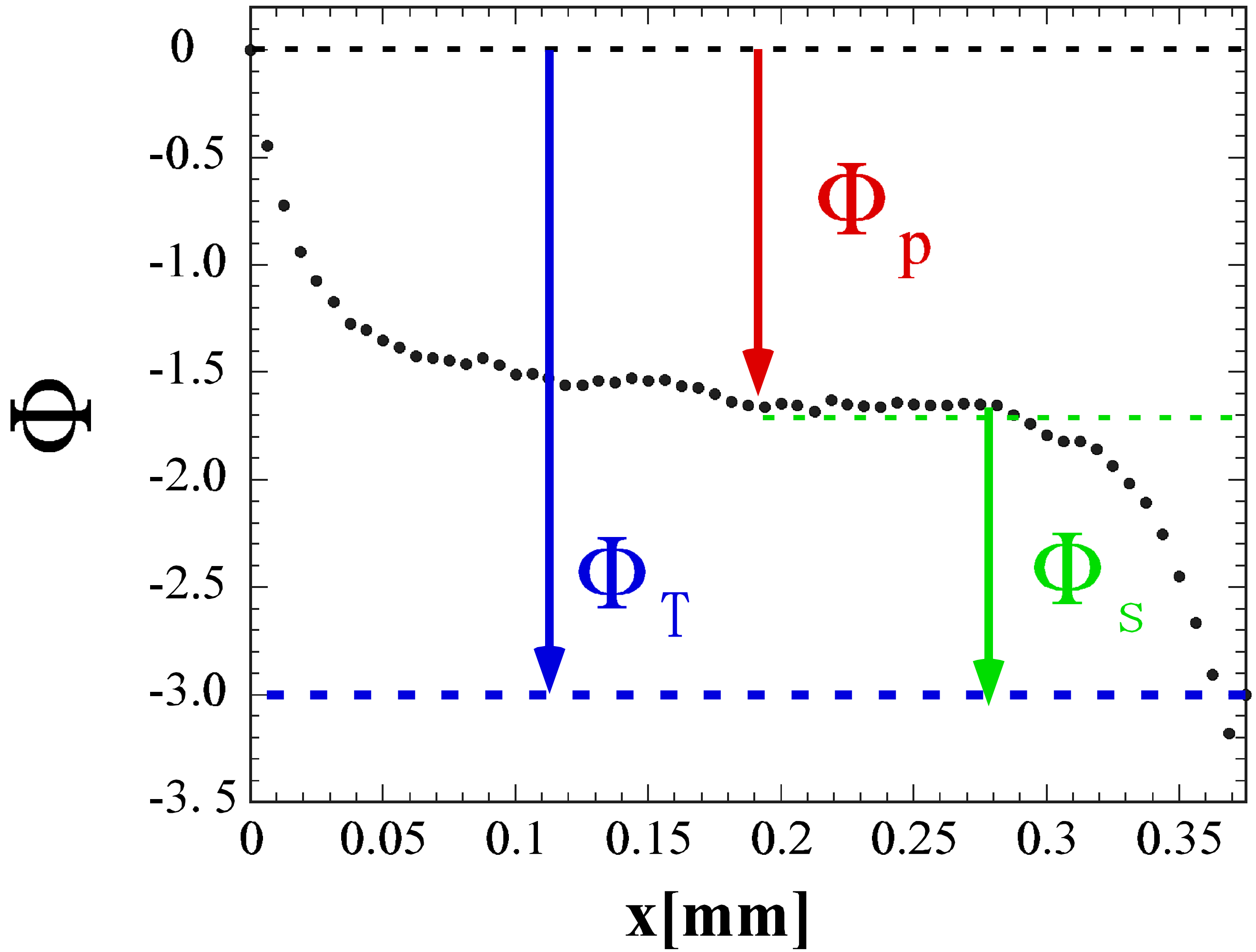
  → Emission current depends on electric properties of material around emissive region

  → The strong magnetic field suppresses emission currents due to small Larmor radius and restraint on orbital deflection of Thermoelectrons

Space potential profile along x

B=0. 1T

at y=0.25mm



Φ_T=−3

Φ_p=−1. 7

Φ_s=−1. 3