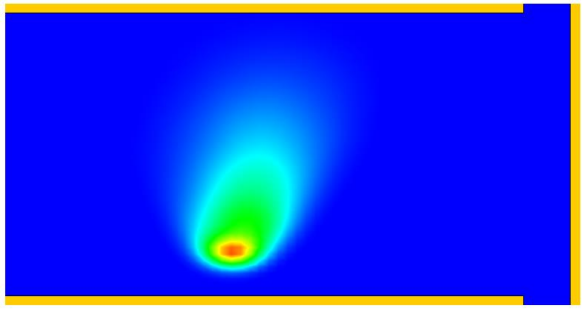
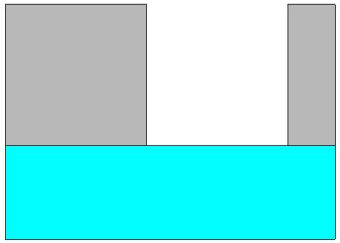
— CASE EXAMPLE —

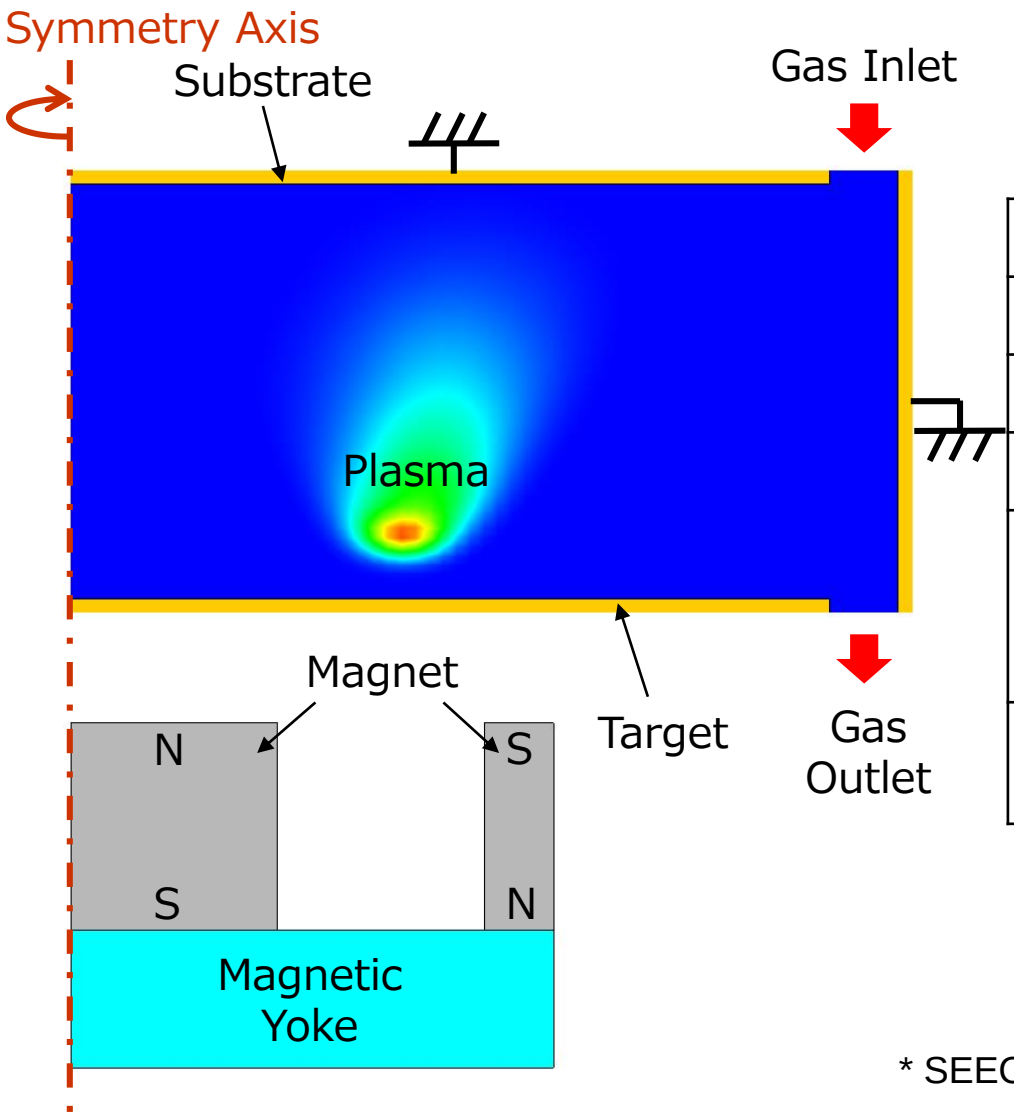
DC Magnetron Sputtering





Model

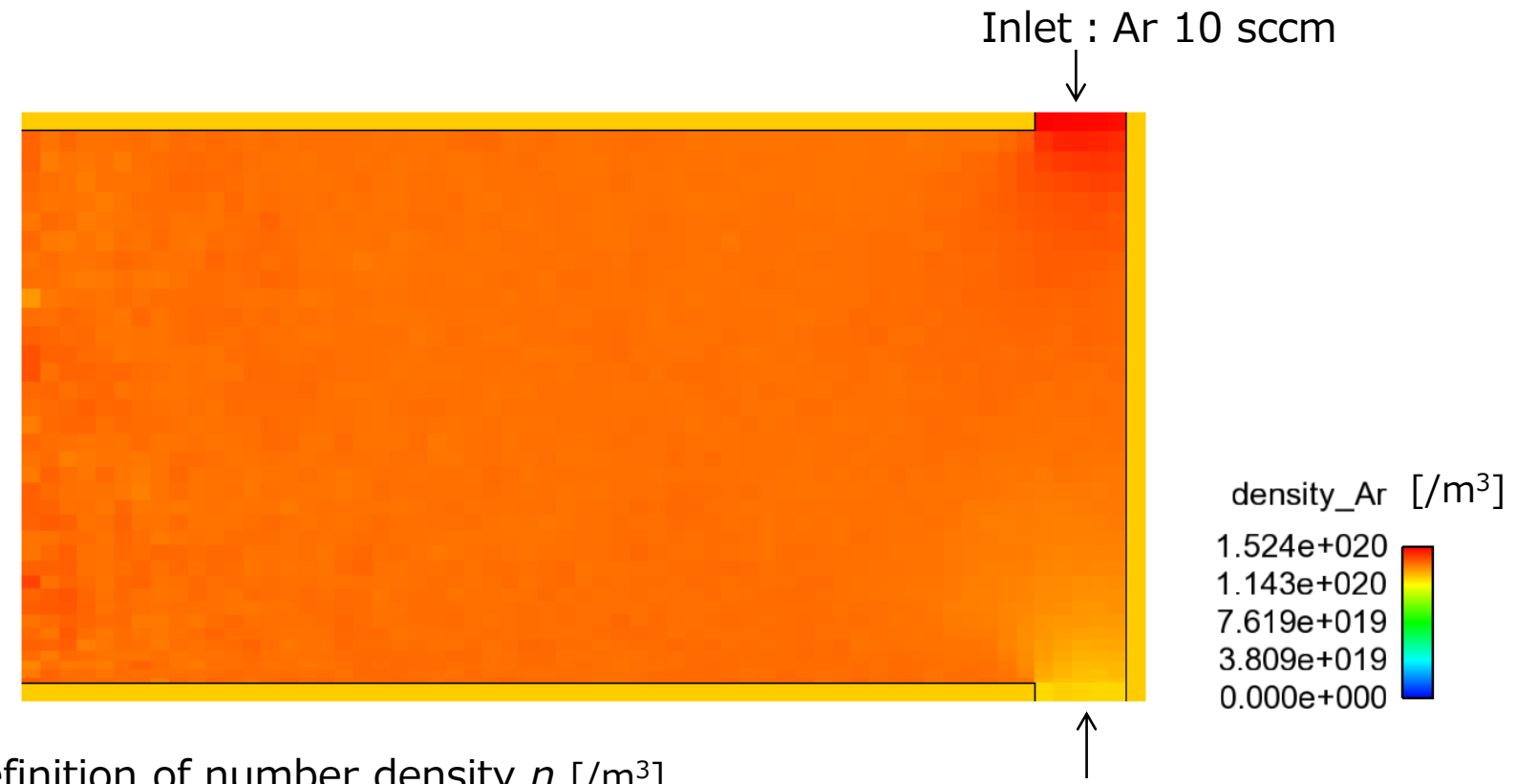
Axi-symmetric model



Gas Inlet		Ar 10 sccm
Gas Outlet		0.5 Pa
Magnet		AlNiCo
Magnetic Yoke		Fe
Target	Material Voltage SEEC*	Ti DC −500 V 0.1
Target-Substrate Distance		30 mm

* SEEC: Secondary Electron Emission Coefficient

Neutral Gas Density



Definition of number density n [/m^3]

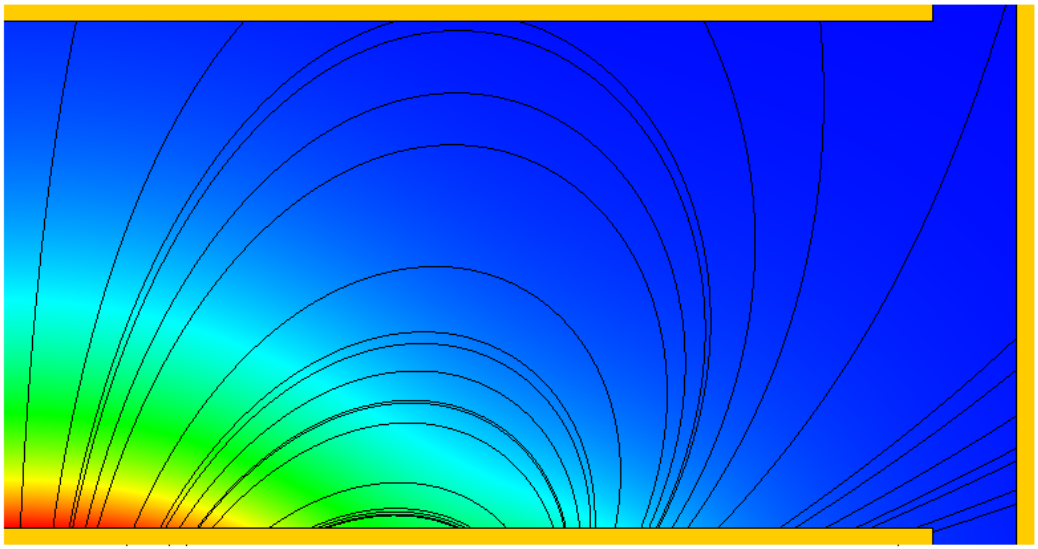
$$n = \frac{N}{V}$$

N : The number of particles per unit

V : Volume of the unit [m^3]

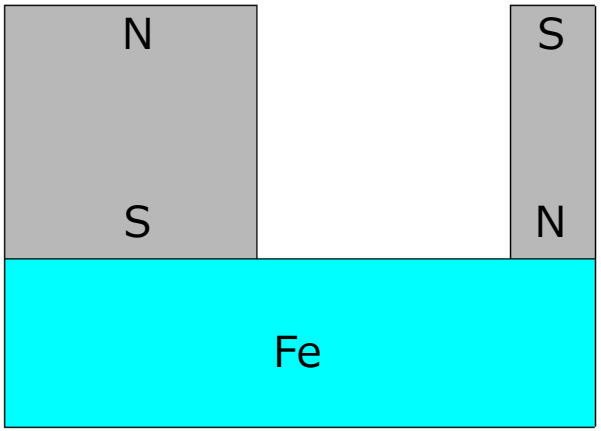
0.5 [Pa] ≒ density 1.2E20 [/m^3] (300K)

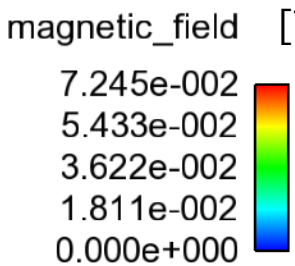
Magnetic Field



Color : Norm of the vector

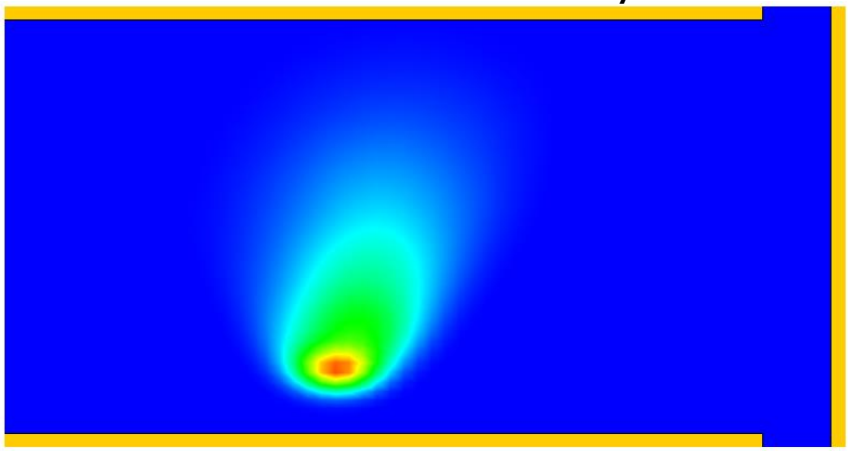
Lines : Magnetic Flux



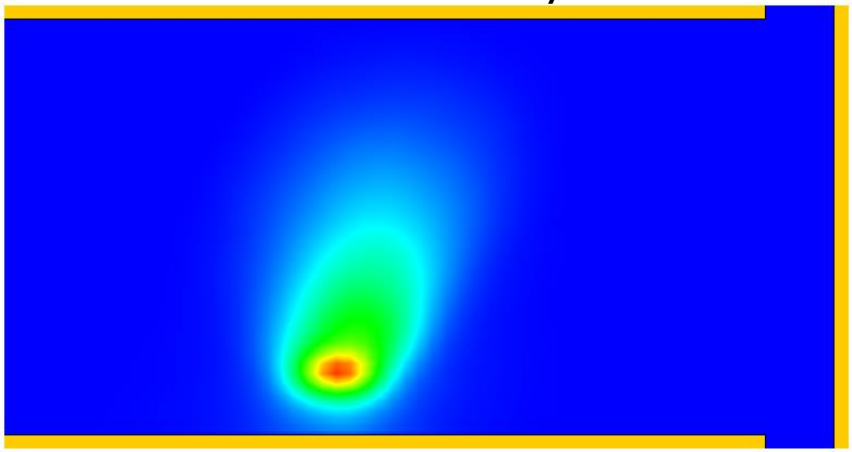


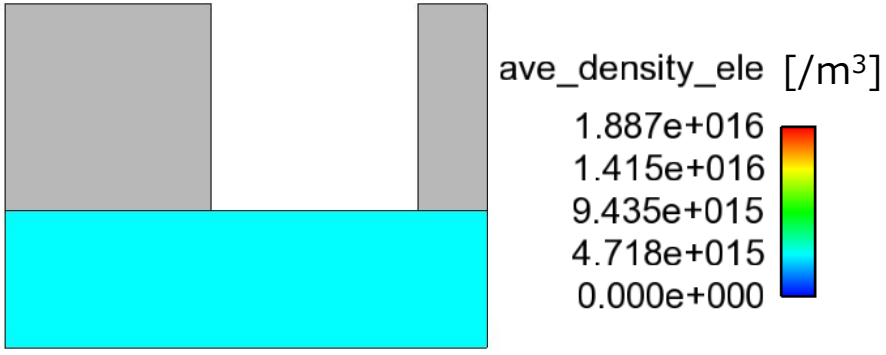
Plasma Density (1)

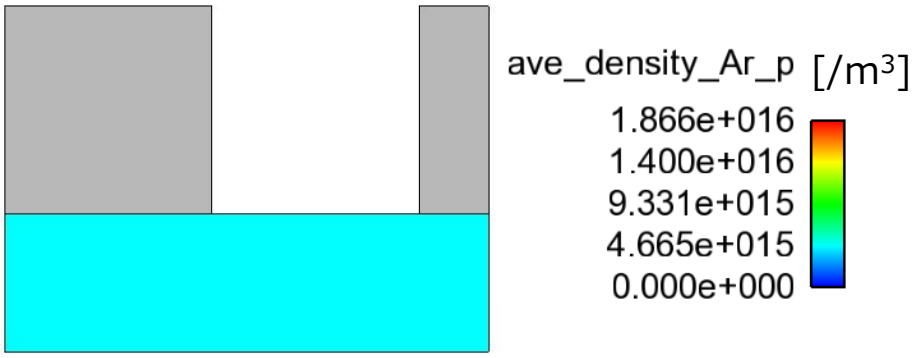
Electron Density



Ar^+ Ion Density







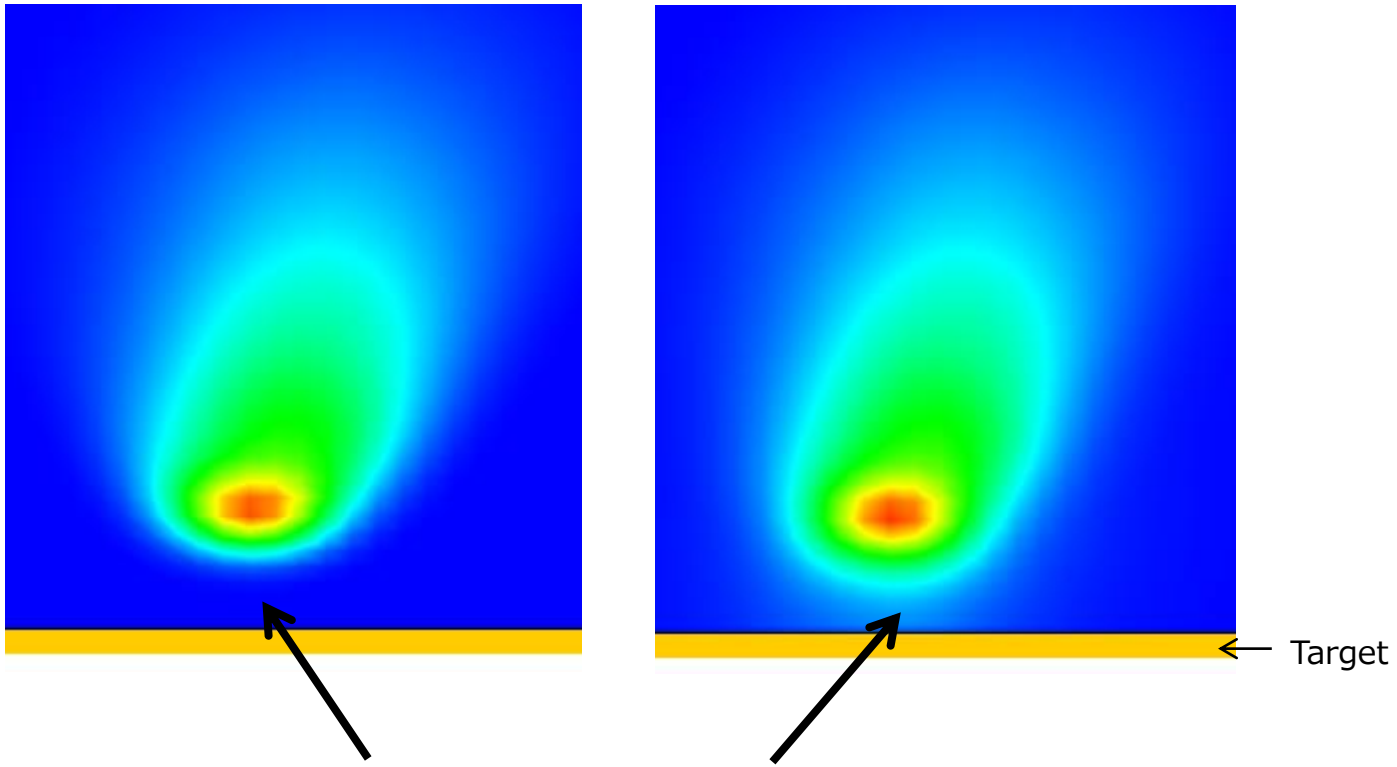
- ✓ Magnetic field traps electrons.
- ✓ Ar^+ distribution is same as electron.

Plasma Density (2)

[Enlarged]

Electron Density

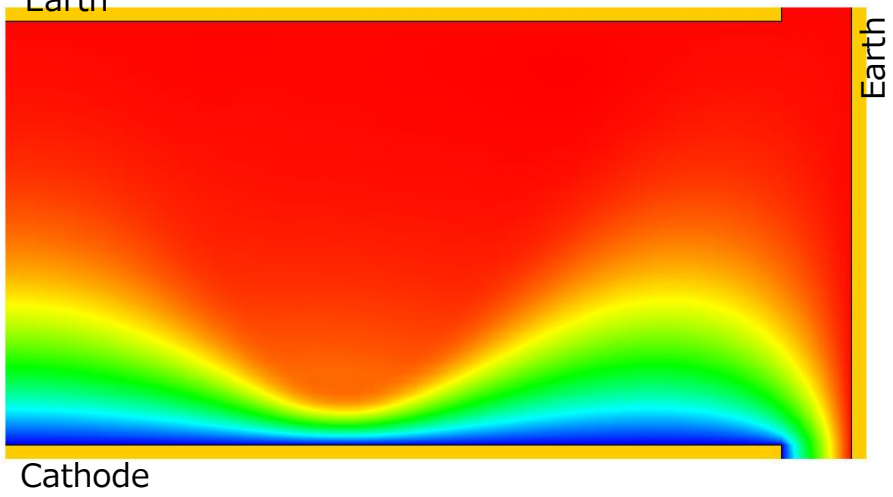
Ar^+ Ion Density



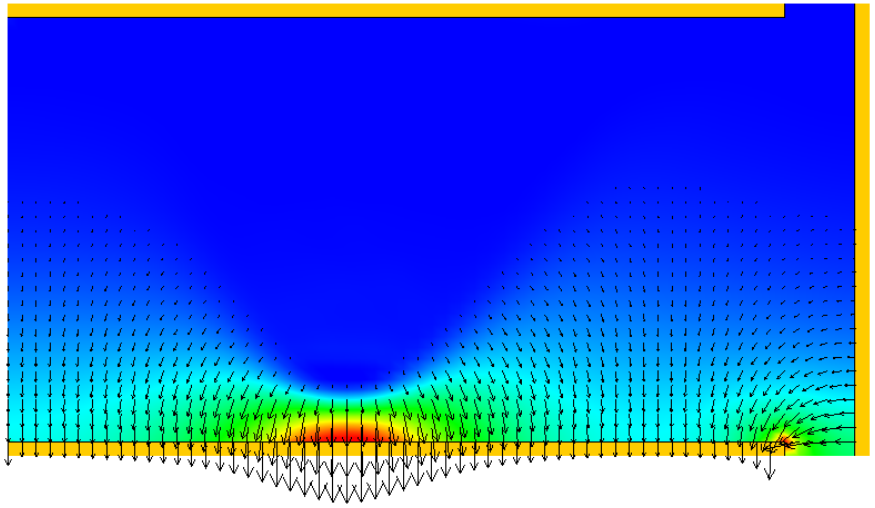
✓ More Ar^+ ion is near the target than electron. (**Ion Sheath**)

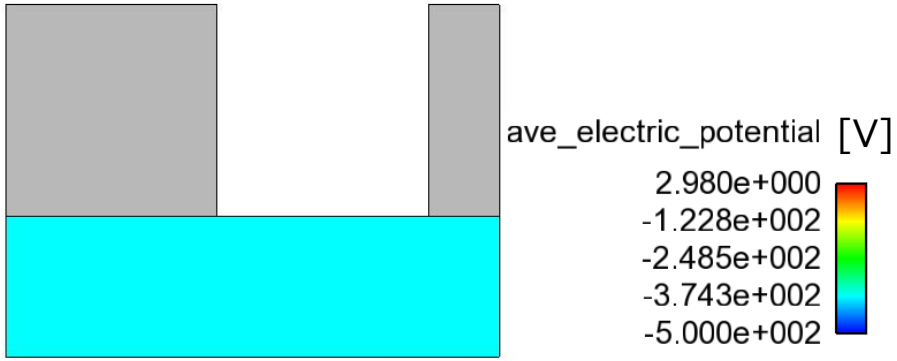
Voltage and Electric Field (1)

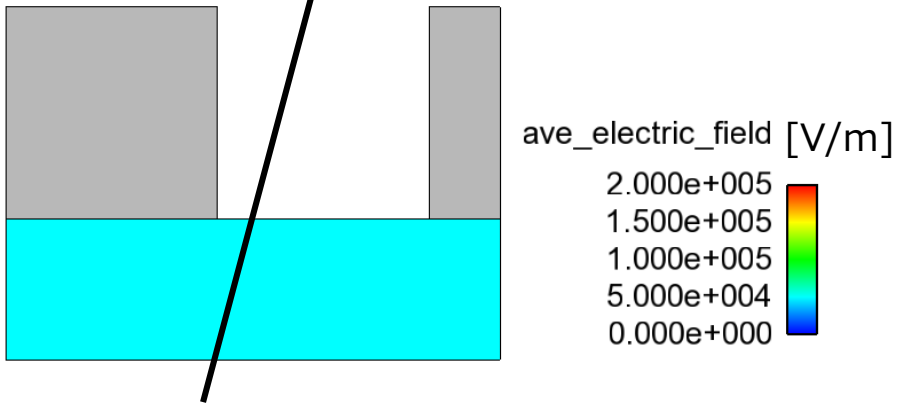
Voltage



Electric Field

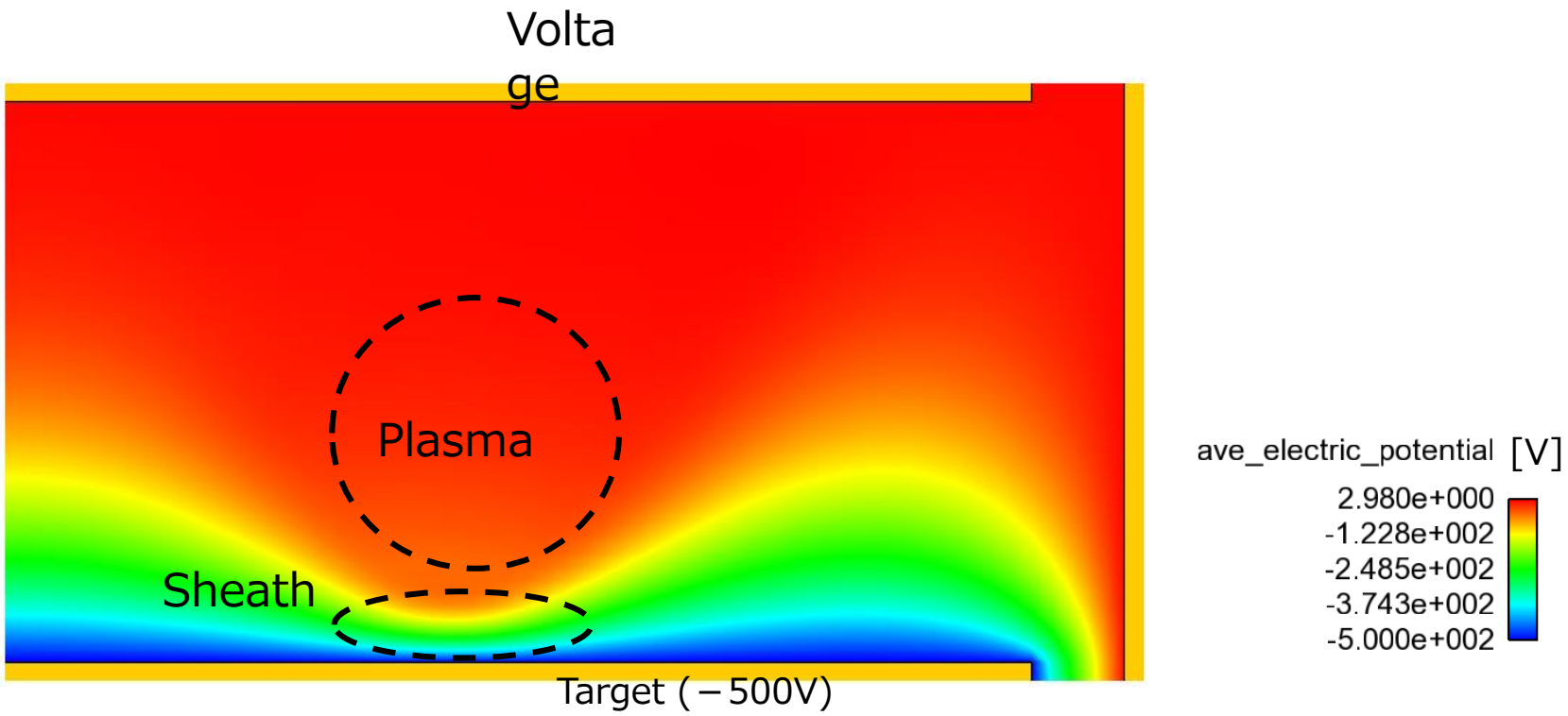






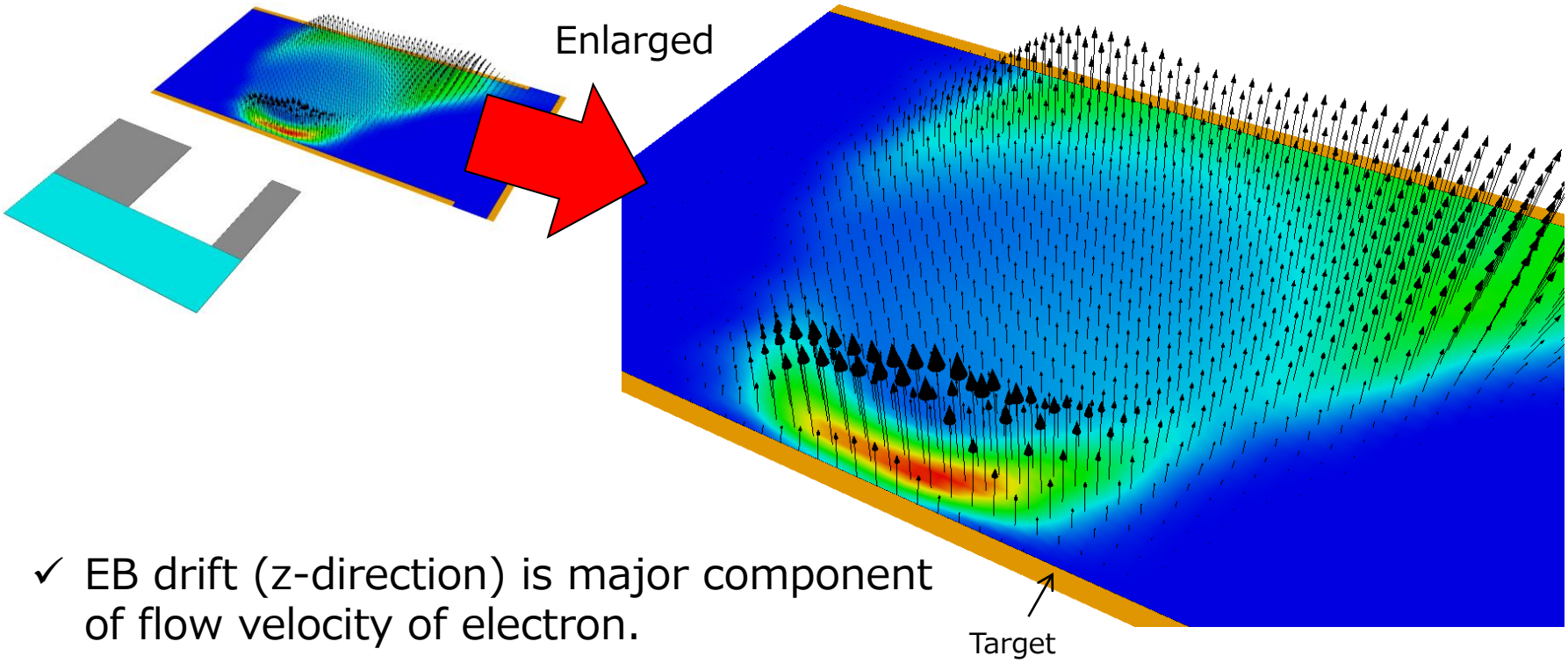
Electric Field near the Sheath is Strong.

Voltage and Electric Field (2)



- ✓ Voltage in plasma is almost zero. (a little positive)
- ✓ Ar^+ ion has 500 eV at maximum, if the ion is accelerated by the electric field in plasma sheath and collide the target.

Electron Flow Velocity

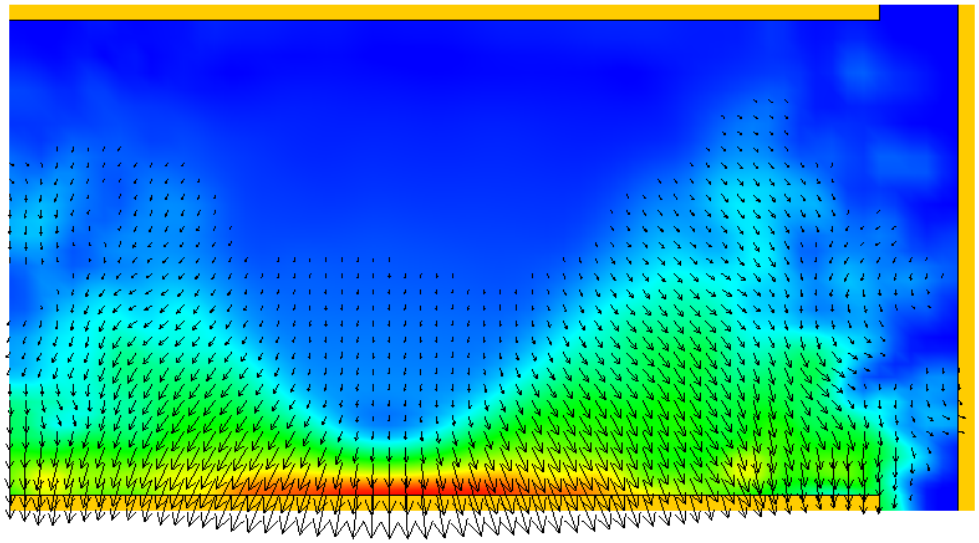


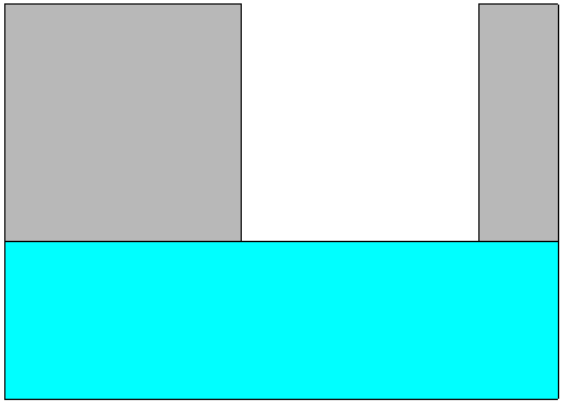
✓ EB drift (z-direction) is major component of flow velocity of electron.

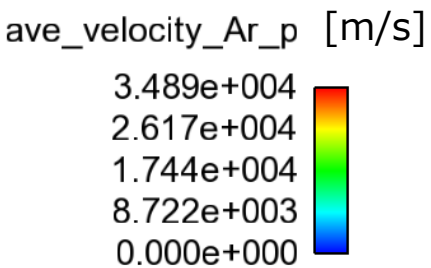
ave_velocity_ele [m/s]
2.497e+006
1.873e+006
1.249e+006
6.244e+005
0.000e+000

cf. Rough estimation of the drift
$E/B \fallingdotseq (2.0\times10^{5}[V/m])/(0.07[T]) = 2.8\times10^{6}[m/s]$

Ion Flow Velocity







- ✓ Ar^+ ion moves along the electric field and the velocity is small because ion is heavy.

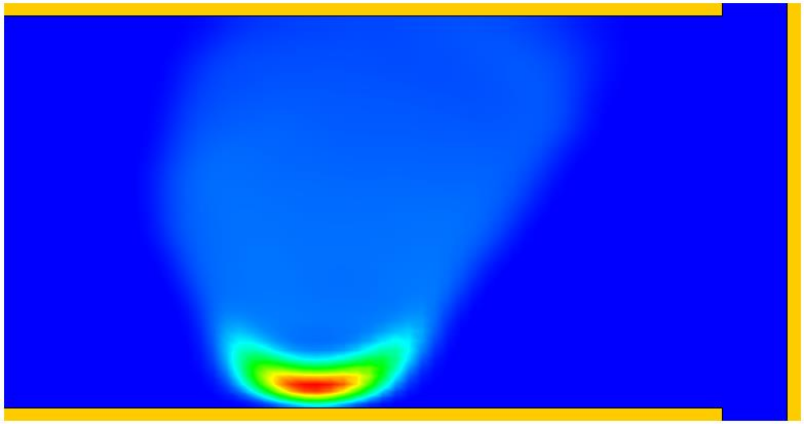
EoM of particle

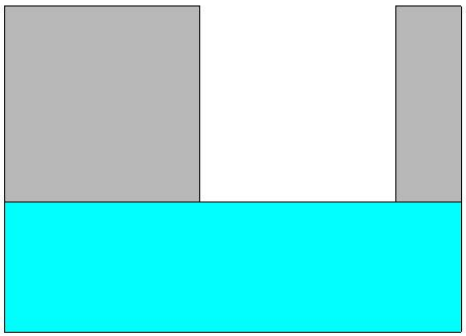
$$m\frac{d\vec{v}}{dt} = q\left(\vec{E} + \vec{v} \times \vec{B}\right)$$

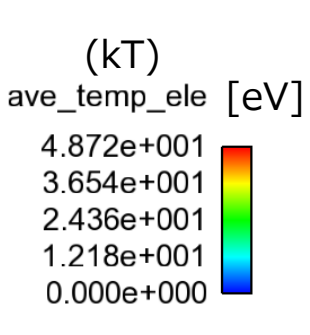
small

Plasma Temperature*

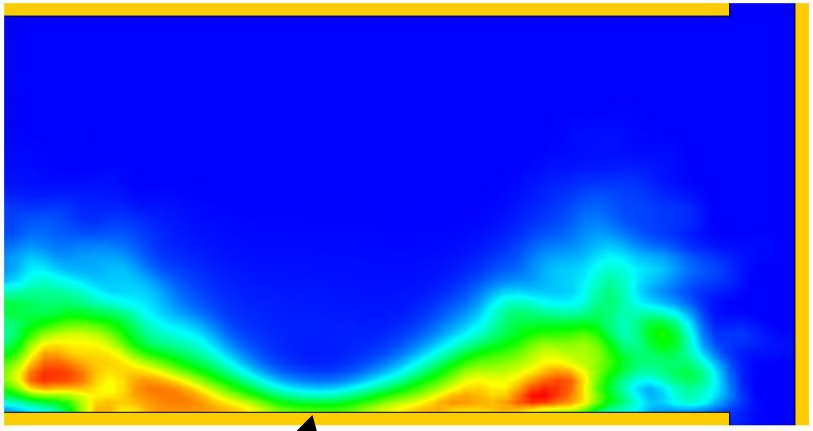
Electron Temperature

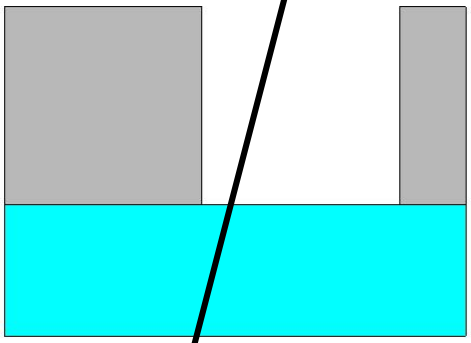


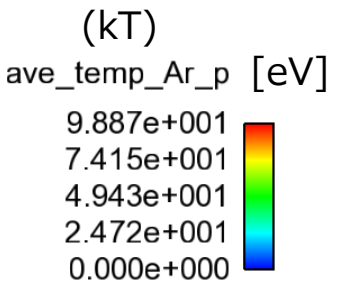




Ar^+ Ion Temperature







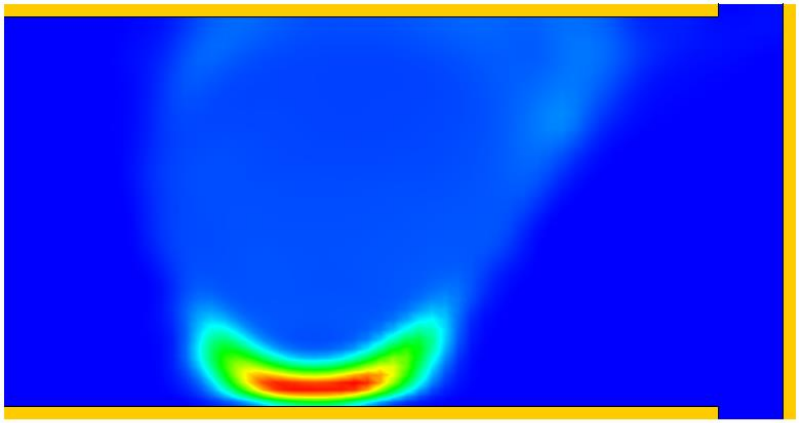
Incident Ar^+ ion to the target is cool.
(vector direction is aligned)

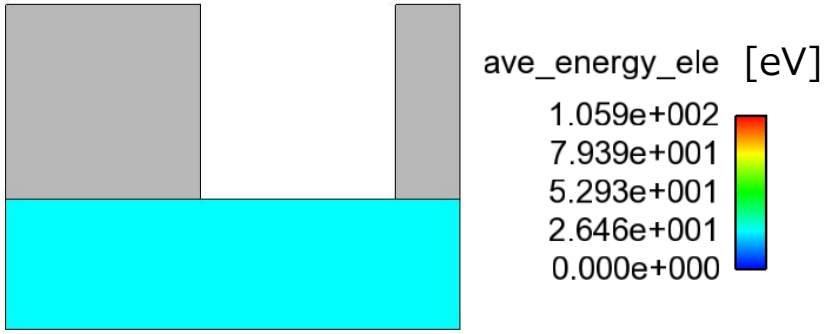
1 [eV] ≒ 11600 [K]

* Same as variance of Maxwell velocity here.

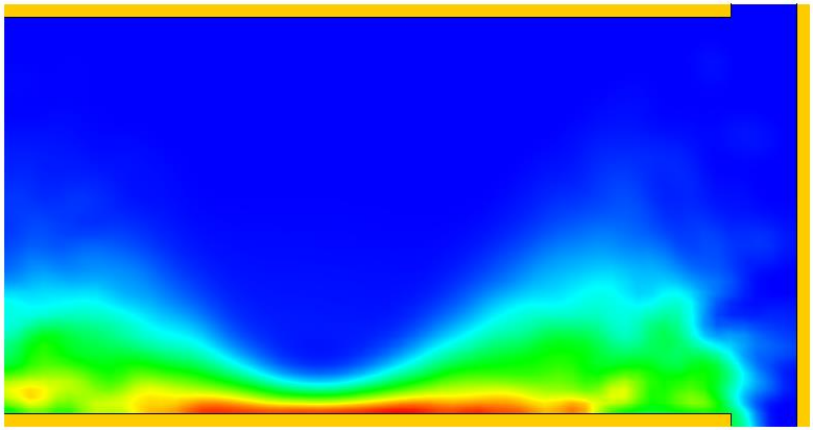
Plasma Energy

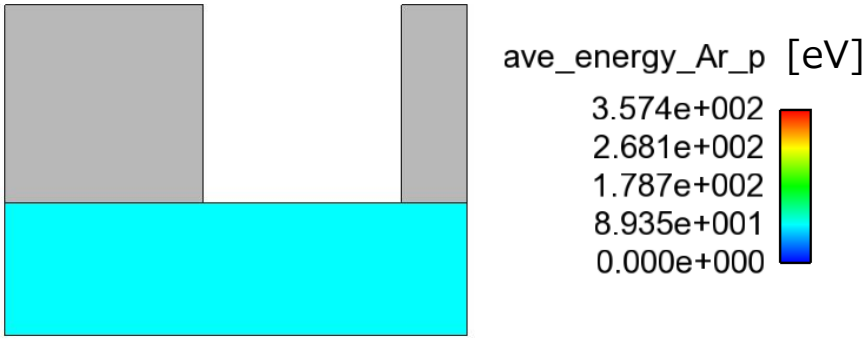
Electron Energy





Ar^+ Ion Energy

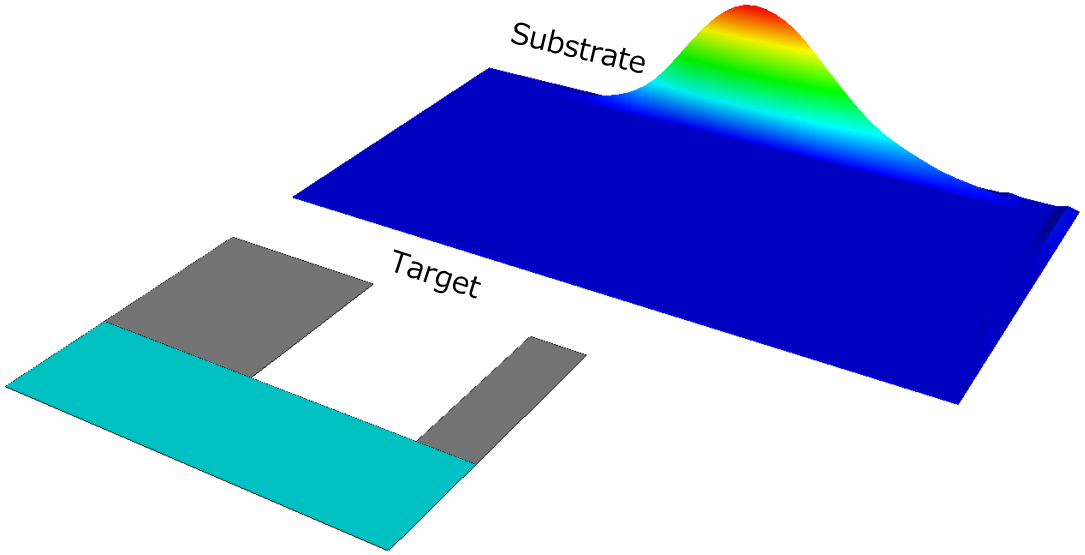




- ✓ Background gas is ionized by electron with high energy.
- ✓ Ar^+ ions with high energy collide to target.

1 [eV] $=1.602\times10^{-19}$ [J]

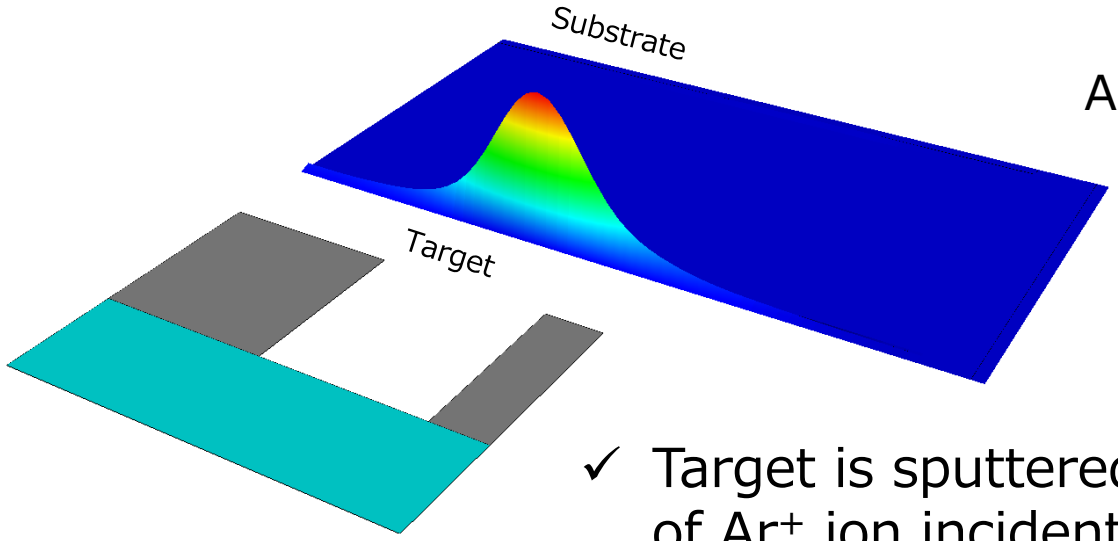
Incident Energy



Electron Incident Energy

ave_flux_energy_ele [W/m²]

1.279e+002
9.591e+001
6.394e+001
3.197e+001
0.000e+000



Ar⁺ Ion Incident Energy

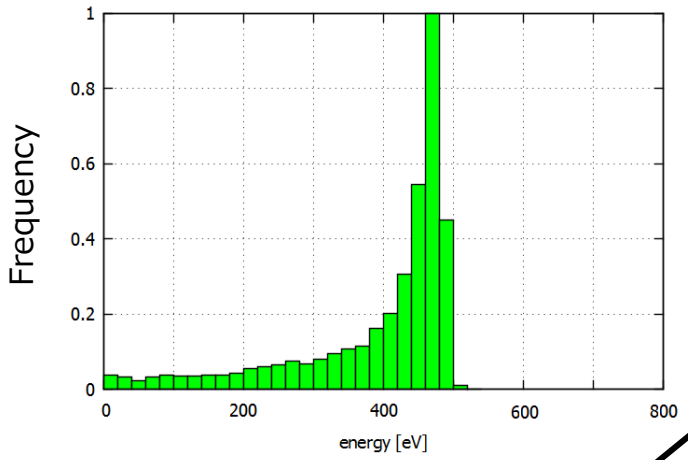
ave_flux_energy_Ar_p [W/m²]

6.465e+003
4.849e+003
3.233e+003
1.616e+003
0.000e+000

✓ Target is sputtered intensely because of Ar^+ ion incident energy.

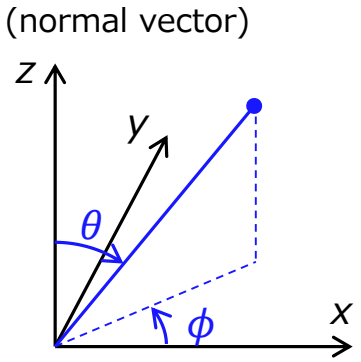
Histograms of Incident Ions

Incident Energy Histogram

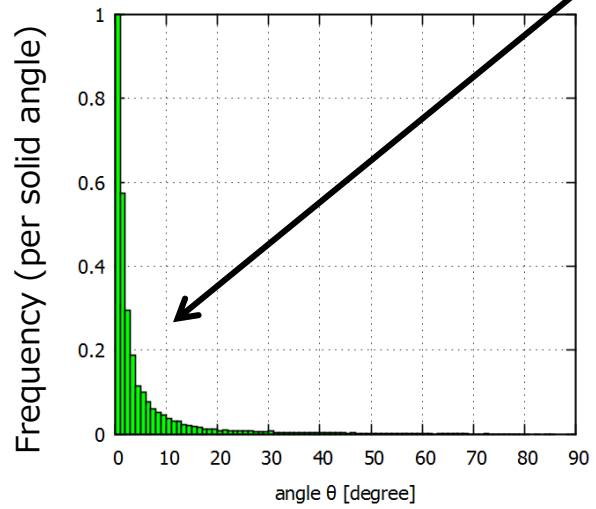


✓ **Ar^+ ions almost enter the target vertically.**

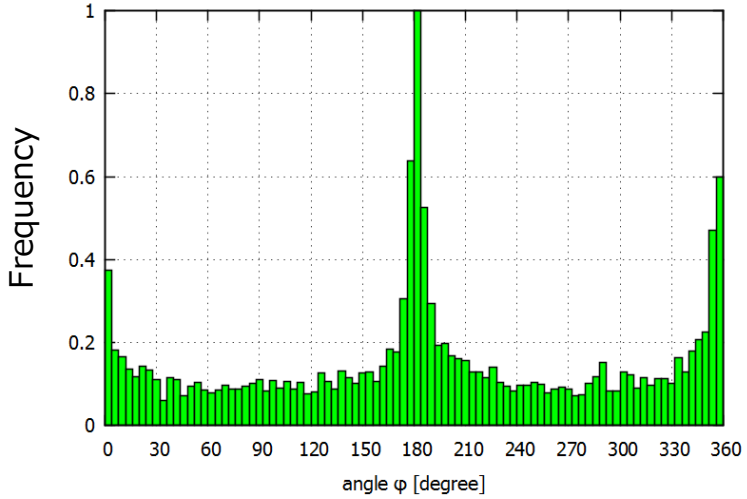
Definitions of Incident Angle θ and Azimuth ϕ



Incident Angle (θ)Histogram

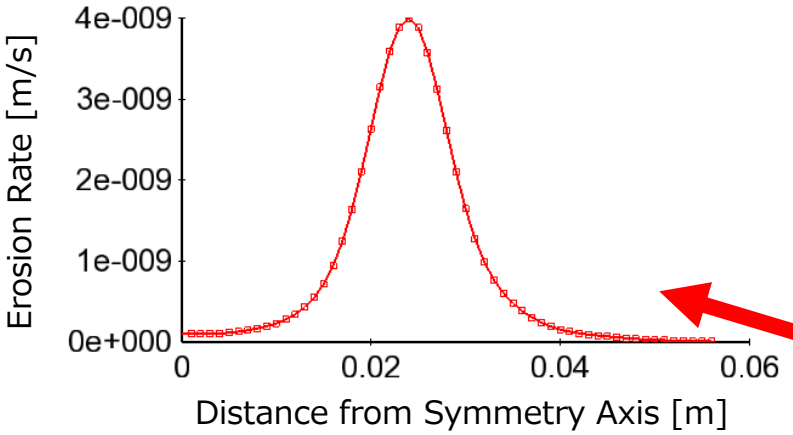


Azimuth (ϕ) Histogram

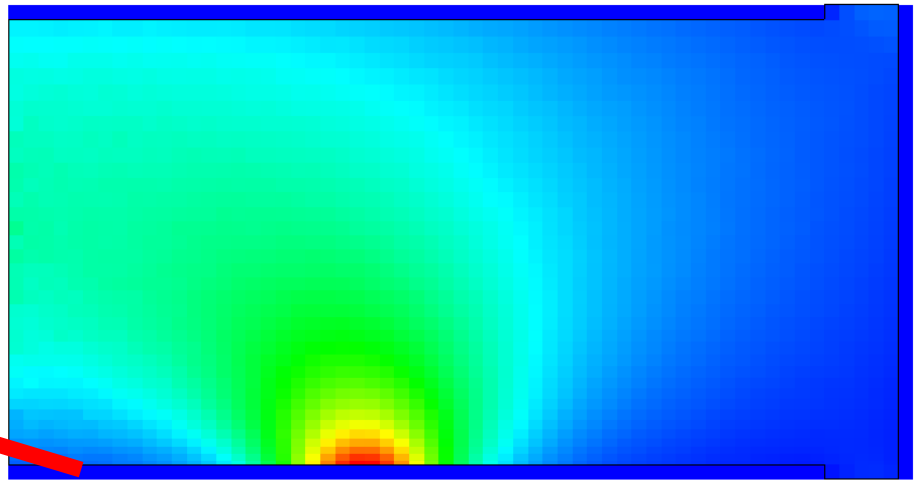


Erosion Rate and Density

Erosion Rate of Ti on Target Surface



Number Density of Ti

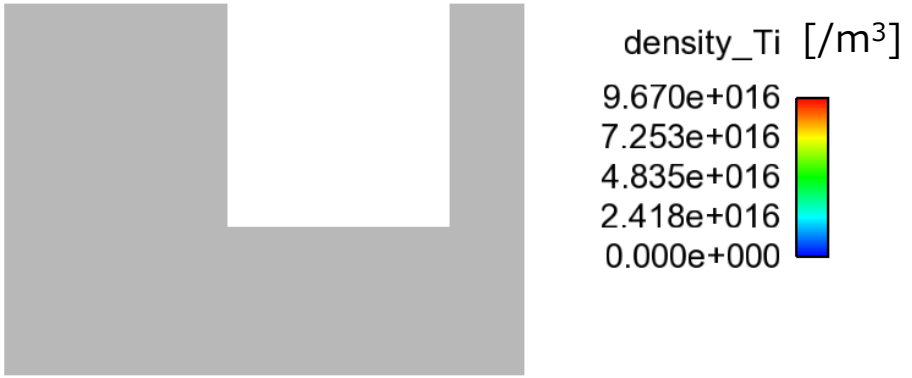


Definition of Erosion/Deposition Rate R [m/s]

$$R = \frac{\Gamma}{n_s}$$

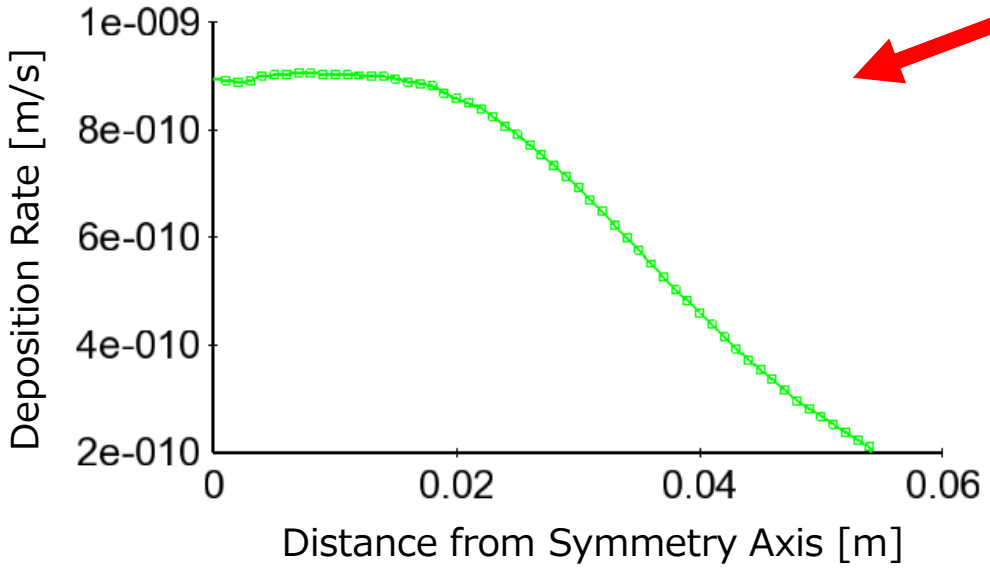
Γ : Particle Flux on Surface [/(m² s)]

n_s : Atomic Density of Target [/m³]

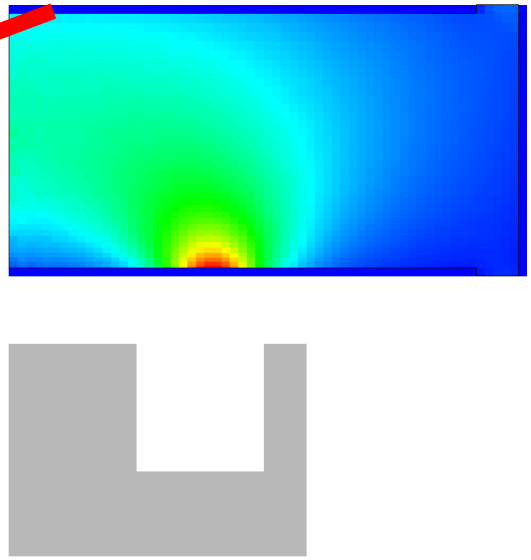


Deposition Rate

Deposition Rate of Ti on Substrate Surface



Number Density of Ti



- ✓ Ti atoms emitted from the target diffuse by collision with Ar, which is background gas.
- ✓ Ti atoms entered into substrate deposit a film.