

Atmospheric Pressure Corona Discharge

Introduction

This model simulates a corona discharge occurring between two coaxially fashioned conductors. The negative electric potential is applied to the inner conductor and the exterior conductor is grounded. The discharge gas simulated is argon at atmospheric pressure.

Model Definition

Figure 1 shows a cross section of the model. By considering a long and uniform coaxial conductor configuration, the model can be viewed as axisymmetric and thus simplified to a 1D problem.

The model presented in the following section is used to simulate the ionization of the neutral gas (Ar) as well as the flux of charged particles (Ar+ and electrons) when the negative electric potential is applied at the inner conductor (cathode). The high electric field generated by the combination of high potential and small conductor curvature radius (inner conductor, r_i) causes electron drift and ionization of the neutral gas surrounding the cathode. The resulting ions generate more electrons through secondary emission at the cathode surface. These electrons are accelerated through a small region away from the cathode, where they can acquire significant energy. This can lead to ionization which creates new electron-ion pairs. The secondary ions migrate toward the cathode where they eject more secondary electrons. This process is responsible for sustaining the discharge.

The model is based on the fluid equations for electrons and ions as well as on Poisson's equation. Secondary electrons generated by ion bombardment of the cathode surface are taken into account. The model uses a Scharfetter–Gummel upwind scheme to eliminate numerical instabilities in the number density of the charged particles associated with the finite element method. This is needed, in particular close to the cathode, where the ion flux is particularly high.



Figure 1: Not-to-scale cross section of the coaxial configuration. The negative potential $(-V_{in})$ is applied at the inner conductor (cathode) and the outer electrode is grounded (anode). The shaded area represents the ionization region created by the positive space charge distribution generated in the vicinity of the cathode.

DOMAIN EQUATIONS

The electron density and mean electron energy are computed by solving the drift-diffusion equations for the electron density and mean electron energy. Convection of electrons due to fluid motion is neglected. For more detailed information on electron transport see the section *Theory for the Drift Diffusion Interface* in the *Plasma Module User's Guide*.

$$\frac{\partial}{\partial t}(n_e) + \nabla \cdot \left[-n_e(\mu_e \bullet \mathbf{E}) - \mathbf{D}_e \bullet \nabla n_e \right] = R_e$$
$$\frac{\partial}{\partial t}(n_e) + \nabla \cdot \left[-n_e(\mu_e \bullet \mathbf{E}) - \mathbf{D}_e \bullet \nabla n_e \right] + \mathbf{E} \cdot \Gamma_e = R_e$$

The electron source R_e and the energy loss due to inelastic collisions R_{ε} are defined later. The electron diffusivity, energy mobility, and energy diffusivity are computed from the electron mobility using the relations

$$\mathbf{D}_e = \mu_e T_e, \, \mu_\varepsilon = \frac{5}{3} \mu_e, \, \mathbf{D}_\varepsilon = \mu_\varepsilon T_e$$

The source coefficients in the above equations are determined by the plasma chemistry using rate coefficients. Suppose that there are M reactions that contribute to the growth or decay of electron density and P inelastic electron-neutral collisions. In general $P \gg M$. In the case of rate coefficients, the electron source term is given by

$$R_e = \sum_{j=1}^{M} x_j k_j N_n n_e$$

where x_j is the mole fraction of the target species for reaction j, k_j is the rate coefficient for reaction j (SI unit: m³/s), and N_n is the total neutral number density (SI unit: 1/m³). The electron energy loss is obtained by summing the collisional energy loss over all reactions:

$$R_{\varepsilon} = \sum_{j=1}^{P} x_j k_j N_n n_e \Delta \varepsilon_j$$

Here $\Delta \varepsilon_j$ is the energy loss from reaction *j* (SI unit: V). The rate coefficients can be computed from cross-section data as the integrals

$$k_k = \gamma \int_0^\infty \varepsilon \sigma_k(\varepsilon) f(\varepsilon) d\varepsilon$$

where $\gamma = (2q/m_e)^{1/2}$ (SI unit: $C^{1/2}/kg^{1/2}$), m_e is the electron mass (SI unit: kg), ε is the energy (SI unit: V), σ_k is the collision cross section (SI unit: m²), and *f* is the electron energy distribution function. In this case, a Maxwellian EEDF is assumed.

For non-electron species, the following equation is solved for the mass fraction of each species:

$$\rho \frac{\partial}{\partial t} (w_k) + \rho (\mathbf{u} \cdot \nabla) w_k = \nabla \cdot \mathbf{j}_k + R_k$$

For detailed information on the transport of the non-electron species see the section Theory for the Heavy Species Transport Interface in the Plasma Module User's Guide.

The electrostatic field is computed using the equation

$$-\nabla \cdot \varepsilon_0 \varepsilon_r \nabla V = \rho$$

The space charge density ρ is automatically computed based on the plasma chemistry specified in the model using the formula

$$\rho = q \left(\sum_{k=1}^{N} Z_k n_k - n_e \right)$$

For detailed information about electrostatics see *Theory for the Electrostatics Interface* in the *Plasma Module User's Guide*.

Boundary Conditions

Electrons are lost to the wall due to random motion within a few mean free paths of the wall and gained due to secondary emission effects, resulting in the boundary condition

$$\mathbf{n} \cdot \Gamma_e = \left(\frac{1}{2} \mathbf{v}_{e, \text{th}} n_e\right) - \sum_p \gamma_p (\Gamma_p \cdot \mathbf{n}) \tag{1}$$

for the electron flux and

$$\mathbf{n} \cdot \Gamma_{\varepsilon} = \left(\frac{5}{6} \mathbf{v}_{e, \text{th}} n_{\varepsilon}\right) - \sum_{p} \varepsilon_{p} \gamma_{p} (\Gamma_{p} \cdot \mathbf{n})$$
(2)

for the electron energy flux. The second term on the right-hand side of Equation 1 is the gain of electrons due to secondary emission effects, γ_p being the secondary emission coefficient. The second term in Equation 2 is the secondary emission energy flux, ε_p being the mean energy of the secondary electrons. For the heavy species, ions are lost to the wall due to surface reactions and the fact that the electric field is directed toward the wall:

$$\mathbf{n} \cdot \mathbf{j}_k = M_w R_k + M_w c_k Z \mu_k (\mathbf{E} \cdot \mathbf{n}) [Z_k \mu_k (\mathbf{E} \cdot \mathbf{n}) > 0]$$

The discharge is driven by the electric potential applied to the inner conductor of the coaxial geometry (at coordinate $r = r_i$).

$$V = V_0 \tanh\left(\frac{t}{\tau}\right)$$

where the function $tanh(t/\tau)$ is used to generate the voltage step function (-1000 V). The other boundary (at coordinate $r = r_0$) is grounded.

Note that, during the simulation, the cathode is submitted to an intense flux of ions that generate an important amount of secondary electrons which, in turn, increase the cathode ion bombardment and so on. In order to prevent this avalanche from increasing indefinitely, a RC circuit has been added in series with the system. In order to model the

circuit addition, the voltage at the inner conductor is modified using the differential equation

$$V = V_0 - \left(I_p R_b + R_b C_b \frac{\partial V}{\partial t} \right)$$

where I_p is defined as

$$I_p = -\int \left(\mathbf{n} \cdot \mathbf{J}_i + \mathbf{n} \cdot \mathbf{J}_e + \frac{\partial}{\partial t} (\mathbf{n} \cdot \mathbf{D}) \right) dS$$

and where $\mathbf{n} \cdot \mathbf{J}_i$ is the normal component of the total ion current density at the wall, $\mathbf{n} \cdot \mathbf{J}_e$ is the normal component of the total electron current density at the wall, and $\mathbf{n} \cdot \mathbf{D}$ the normal electrical displacement at the surface.

PLASMA CHEMISTRY

Argon is an attractive gas to use in a benchmark problem because only a handful of reactions and a few species need to be considered. Table 1 lists the chemical reactions considered.

Reaction	Formula	Туре	$\Delta\epsilon$ (eV)	k _f (m ³ /(s⋅mol))
1	e+Ar=>e+Ar	Elastic	0	-
2	e+Ar=>e+Ars	Excitation	11.5	-
3	e+Ars=>e+Ar	Superelastic	-11.5	-
4	e+Ar=>2e+Ar+	Ionization	15.8	-
5	e+Ars=>2e+Ar+	Ionization	4.24	-
6	Ar+Ars=>Ar+Ar	Reaction	-	1807
7	Ars+Ars=>Ars+Ar	Reaction	-	2.3·10 ⁷

TABLE I: TABLE OF COLLISIONS AND REACTIONS MODELED.

Initially, a small number of seed electrons are present. These electrons are necessary in order to initiate the discharge. In addition to the volumetric reactions, the following surface reactions are implemented:

TABLE 2:	TABLE	OF	SURFACE	REACTIONS.
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Reaction	Formula	Sticking coefficient
I	Ars=>Ar	1
2	Ar+=>Ar	I

When the ion atoms reach the wall, they are assumed to change back to neutral argon atoms and donate their charge to the wall. Note that the secondary emission coefficient is set to 0.2 on the cathode boundary (at coordinate $r = r_i$) and to 0 at the outer electrode (at coordinate $r = r_0$). The mean electron energy of the secondary electron is set to 4 eV.

Results and Discussion

When solving the problem, you can choose to plot the electron and ion density as the solver runs. Doing so, you can observe the behavior of the charged species as the model is solving.

Looking at the evolution of the densities during the solving process shows that the gas is initially weekly ionized (electrons and ions having relatively low densities compared to neutral atoms). As the negative voltage is applied to the cathode, the highly mobile electrons are accelerated toward the anode leaving behind a positively charged gas in the cathode vicinity. With increasing negative potential, ion bombardment becomes more persistent on the cathode surface, which generates more secondary electrons, ionizing more neutral atoms, and engendering greater ion current. As the negative potential rises, the population of charged particles becomes larger as a consequence of this avalanche effect.

As the ion current becomes more significant, the RC circuit reduces the cathode negative potential such that an equilibrium is reached between the generation of the charged particles, preventing the transition of the plasma into an arcing regime.

Figure 2 shows the electron and ion densities at the end of the simulation (t = 0.1 s). Note that the figure is plotted on a log-log scale. In the figure, you can see that the ion density is approximately three orders of magnitude higher than the electron density in the vicinity of the cathode. The tiny positive space charge distribution generated by the ion density defines an ionization region that screens the cathode potential from the anode. This can be observed by displaying the electric potential along the radius of the coaxial assembly; see Figure 3.



Figure 2: Plot of electron (blue) and ion (green) number density at the end of the simulation (t = 0.1 s).



Figure 3: Electric potential along the radius of the coaxial assembly at the end of the simulation (t = 0.1 s).

The high voltage and important current density at the cathode enhance the electron temperature near the electrode, thus boosting ionization of the neutral atoms in the ionization zone. This can be seen in Figure 4, which displays the electron temperature at the end of the simulation.



Figure 4: Electron temperature along the radius of the assembly at the end of the simulation (t = 0.1 s).

To see the effect of the RC circuit on the system, plot the secondary electron flux as a function of time at the cathode surface; see Figure 5. A close look at the figure shows a rapid rise of the flux that tends to stabilize as the circuit sees higher currents. Figure 6 also shows the potential at both electrodes as a function of time. Comparing figure Figure 5 with Figure 6 reveals the effect of the circuit on both potential and secondary emission at the cathode surface. You can also observe a similar effect by plotting the electron current density at the electrodes, Figure 6. Doing so shows a direct relation between the cathode secondary emission (positive current flow), the anode recombination (negative flow), and the RC circuit. Figure 7 displays a surface plot of the logarithm of the electron density at the last time step.



Figure 5: Secondary emission flux along time at the cathode.



Figure 6: Potential at the electrodes as a function of time.



Figure 7: Electron current density at the electrodes as a function of time.



Figure 8: 2D electron density (log of n_e) at the last time step.

Application Library path: Plasma_Module/Direct_Current_Discharges/ corona_discharge_1d

Modeling Instructions

From the File menu, choose New.

NEW

In the New window, click Model Wizard.

MODEL WIZARD

- I In the Model Wizard window, click 🔶 ID Axisymmetric.
- 2 In the Select Physics tree, select Plasma>Plasma (plas).
- 3 Click Add.

- 4 Click 🔿 Study.
- 5 In the Select Study tree, select General Studies>Time Dependent.
- 6 Click 🗹 Done.

To set up this model, you need access to some advanced settings.

PLASMA (PLAS)

Solve this model using the finite volume method and a Scharfetter-Gummel scheme. You can switch from the finite element method to the finite volume method by suitable choices in the **Discretization** section.

- I In the Model Builder window, under Component I (compl) click Plasma (plas).
- 2 In the Settings window for Plasma, click to expand the Discretization section.
- 3 From the Formulation list, choose Finite volume (constant shape function).

GLOBAL DEFINITIONS

Parameters 1

- I In the Model Builder window, under Global Definitions click Parameters I.
- 2 In the Settings window for Parameters, locate the Parameters section.

3 In the table, enter the following settings:

Name	Expression	Value	Description
VO	1000[V]	1000 V	Voltage

GEOMETRY I

Follow the steps below to create the model geometry: a simple 1D geometry consisting of a single domain bounded by the cathode (left, inner conductor) and the anode (right, outer conductor).

- I In the Model Builder window, under Component I (compl) click Geometry I.
- 2 In the Settings window for Geometry, locate the Units section.
- 3 From the Length unit list, choose cm.

Interval I (i1)

- I Right-click Component I (compl)>Geometry I and choose Interval.
- 2 In the Settings window for Interval, locate the Interval section.

3 In the table, enter the following settings:

Coordinates (cm)

0.2 5

4 Click 🟢 Build All Objects.

PLASMA (PLAS)

Load the argon cross sections from file. They form the basis of the plasma chemistry under investigation. To fix the species data, load the argon preset for each species.

Cross Section Import 1

- I In the Physics toolbar, click 💥 Global and choose Cross Section Import.
- 2 In the Settings window for Cross Section Import, locate the Cross Section Import section.
- 3 Click Browse.
- **4** Browse to the model's Application Libraries folder and double-click the file Ar_xsecs.txt.
- 5 Click Import.

When solving any type of reacting flow problem one species must always be chosen to fulfill the mass constraint. This should be taken as the species with the largest mass fraction.

Species: Ar

- I In the Model Builder window, click Species: Ar.
- 2 In the Settings window for Species, locate the Species Formula section.
- 3 Select the From mass constraint check box.

When solving a plasma problem the plasma must initially be charge neutral. COMSOL automatically computes the initial concentration of a selected ionic species such that the initial electroneutrality constraint is satisfied. Now let the initial number density of argon ions be the same as the initial number of electrons. This forces the plasma to be initially charge neutral.

Species: Ar+

- I In the Model Builder window, click Species: Ar+.
- 2 In the Settings window for Species, locate the Species Formula section.
- **3** Select the **Initial value from electroneutrality constraint** check box.
- 4 Locate the General Parameters section. From the Preset species data list, choose Ar.

Species: Ar

- I In the Model Builder window, click Species: Ar.
- 2 In the Settings window for Species, locate the General Parameters section.
- 3 From the Preset species data list, choose Ar.

Species: Ars

- I In the Model Builder window, click Species: Ars.
- 2 In the Settings window for Species, locate the General Parameters section.
- 3 From the Preset species data list, choose Ar.

Now add two more regular reactions that describe how electronically excited argon atoms are consumed on the volumetric level. The rate coefficients for these reactions are taken from the literature.

Reaction I

- I In the Physics toolbar, click Domains and choose Reaction.
- 2 In the Settings window for Reaction, locate the Reaction Formula section.
- **3** In the **Formula** text field, type Ar+Ars=>Ar+Ar.
- **4** Locate the **Reaction Parameters** section. In the k^{f} text field, type 1807.

Reaction 2

- I In the Physics toolbar, click Domains and choose Reaction.
- 2 In the Settings window for Reaction, locate the Reaction Formula section.
- 3 In the Formula text field, type Ars+Ars=>Ars+Ar.
- 4 Locate the **Reaction Parameters** section. In the k^{f} text field, type 2.3e7.

Surface reactions must always be included in a plasma model because they describe how ionic, excited, and radical species interact with the wall.

Surface Reaction 1

- I In the Physics toolbar, click Boundaries and choose Surface Reaction.
- 2 In the Settings window for Surface Reaction, locate the Reaction Formula section.
- 3 In the Formula text field, type Ars=>Ar.
- 4 Locate the Boundary Selection section. From the Selection list, choose All boundaries.

Secondary emission of electrons is important to sustain a DC discharge. In this example, add a secondary emission coefficient on the left wall (cathode).

Surface Reaction 2

I In the Physics toolbar, click — Boundaries and choose Surface Reaction.

- 2 In the Settings window for Surface Reaction, locate the Reaction Formula section.
- 3 In the Formula text field, type Ar+=>Ar.
- **4** Select Boundary 1 only.
- **5** Locate the **Secondary Emission Parameters** section. In the γ_i text field, type 0.2.
- **6** In the ε_i text field, type 4.

Surface Reaction 3

- I In the Physics toolbar, click Boundaries and choose Surface Reaction.
- 2 In the Settings window for Surface Reaction, locate the Reaction Formula section.
- 3 In the Formula text field, type Ar+=>Ar.
- **4** Select Boundary 2 only.
- 5 In the Model Builder window, click Plasma (plas).
- 6 In the Settings window for Plasma, locate the Plasma Properties section.
- 7 Select the Use reduced electron transport properties check box.
- 8 Locate the Vertical Height section. In the d_z text field, type 0.02[m].

Plasma Model I

- I In the Model Builder window, click Plasma Model I.
- 2 In the Settings window for Plasma Model, locate the Electron Density and Energy section.
- **3** In the $\mu_e N_n$ text field, type 4e24.

Ground I

- I In the Physics toolbar, click Boundaries and choose Ground.
- **2** Select Boundary 2 only.

Now, add an RC circuit in series with the system. The role of the circuit is to limit the current at the cathode and avoid the arcing regime.

Metal Contact 1

- I In the Physics toolbar, click Boundaries and choose Metal Contact.
- 2 Select Boundary 1 only.
- 3 In the Settings window for Metal Contact, locate the Terminal section.
- **4** In the V_0 text field, type V0.
- 5 Locate the Circuit Settings section. From the Circuit type list, choose Series RC circuit.

Wall I

I In the Physics toolbar, click — Boundaries and choose Wall.

2 In the Settings window for Wall, locate the Boundary Selection section.

3 From the Selection list, choose All boundaries.

MESH I

Meshing is a critical step in any plasma model. A fine mesh is needed close to the electrodes to capture the separation of space charge between the electrons and ions close to the wall.

Edge I

In the Mesh toolbar, click \triangle Edge.

Distribution I

- I Right-click Edge I and choose Distribution.
- 2 In the Settings window for Distribution, locate the Distribution section.
- **3** From the **Distribution type** list, choose **Predefined**.
- 4 In the Number of elements text field, type 500.
- 5 In the Element ratio text field, type 400.
- 6 From the Growth formula list, choose Geometric sequence.
- 7 Select the Symmetric distribution check box.
- 8 Click 📗 Build All.

STUDY I

Compute an initial solution to generate the default plots and then set them up to show the electron and ion density while the solver runs.

I In the Model Builder window, right-click Study I and choose Get Initial Value for Step.

RESULTS

Electron Density (plas)

Set up an electron and ion density plot.

- I In the Settings window for ID Plot Group, locate the Plot Settings section.
- 2 Select the x-axis label check box.
- 3 Select the y-axis label check box.
- 4 In the associated text field, type Density (1/m³).
- 5 Locate the Legend section. From the Position list, choose Lower right.

Electrons

- I In the Model Builder window, expand the Electron Density (plas) node, then click Line Graph I.
- 2 In the Settings window for Line Graph, click to expand the Legends section.
- 3 Select the Show legends check box.
- 4 From the Legends list, choose Manual.
- 5 Click to expand the Title section. From the Title type list, choose None.
- 6 Locate the Legends section. In the table, enter the following settings:

Legends

Electrons

- 7 Right-click Line Graph I and choose Rename.
- 8 In the Rename Line Graph dialog box, type Electrons in the New label text field.
- 9 Click OK.

lons

- I Right-click Electrons and choose Duplicate.
- 2 Right-click Electrons I and choose Rename.
- 3 In the Rename Line Graph dialog box, type Ions in the New label text field.
- 4 Click OK.
- 5 In the Settings window for Line Graph, locate the y-Axis Data section.
- **6** In the **Expression** text field, type plas.n_wAr_1p.
- 7 Locate the Legends section. In the table, enter the following settings:

Legends

Ions

Electron and Ion Number Density

- I In the Model Builder window, click Electron Density (plas).
- 2 In the Settings window for ID Plot Group, locate the Data section.
- **3** From the **Time selection** list, choose **Last**.
- 4 Right-click Electron Density (plas) and choose Rename.
- **5** In the **Rename ID Plot Group** dialog box, type Electron and Ion Number Density in the **New label** text field.
- 6 Click OK.

- 7 Click the **y-Axis Log Scale** button in the **Graphics** toolbar.
- 8 Click the x-Axis Log Scale button in the Graphics toolbar. Now set up the last two default plots.

Electron Temperature (plas)

- I In the Settings window for ID Plot Group, locate the Data section.
- 2 From the Time selection list, choose Last.

Line Graph 1

- I In the Model Builder window, expand the Electron Temperature (plas) node, then click Line Graph I.
- 2 In the Settings window for Line Graph, locate the Title section.
- **3** From the **Title type** list, choose **None**.

Electric Potential (plas)

- I In the Model Builder window, click Electric Potential (plas).
- 2 In the Settings window for ID Plot Group, locate the Data section.
- 3 From the Time selection list, choose Last.

Line Graph 1

- I In the Model Builder window, expand the Electric Potential (plas) node, then click Line Graph I.
- 2 In the Settings window for Line Graph, locate the Title section.
- **3** From the **Title type** list, choose **None**.
- 4 Locate the y-Axis Data section. Select the Description check box.
- **5** In the associated text field, type Electron potential.

STUDY I

Step 1: Time Dependent

- I In the Model Builder window, under Study I click Step I: Time Dependent.
- 2 In the Settings window for Time Dependent, locate the Study Settings section.
- 3 In the **Output times** text field, type 0 .
- 4 Click Range.
- 5 In the Range dialog box, choose Number of values from the Entry method list.
- 6 In the Start text field, type -8.
- 7 In the **Stop** text field, type 0.

- 8 In the Number of values text field, type 50.
- 9 From the Function to apply to all values list, choose explo(x) –
 Exponential function (base 10).
- IO Click Add.
- **II** In the **Settings** window for **Time Dependent**, click to expand the **Results While Solving** section.
- **12** Select the **Plot** check box.
- **I3** In the **Home** toolbar, click **= Compute**.

RESULTS

Electric Potential (plas) Now plot the electric potential on the electrodes.

ID Plot Group 4

In the Home toolbar, click 🚛 Add Plot Group and choose ID Plot Group.

Point Graph 1

- I Right-click ID Plot Group 4 and choose Point Graph.
- 2 In the Settings window for Point Graph, locate the Selection section.
- 3 From the Selection list, choose All boundaries.
- 4 Locate the y-Axis Data section. In the Expression text field, type V.
- 5 Click to expand the Legends section. Select the Show legends check box.
- 6 From the Legends list, choose Manual.
- 7 In the table, enter the following settings:

Legends

Cathode

Anode

- 8 Locate the y-Axis Data section. Select the Description check box.
- 9 Click to expand the Title section. From the Title type list, choose None.

Electric Potential on Electrodes

- I In the Model Builder window, click ID Plot Group 4.
- 2 In the Settings window for ID Plot Group, locate the Legend section.
- 3 From the **Position** list, choose **Lower right**.

- 4 Right-click ID Plot Group 4 and choose Rename.
- 5 In the Rename ID Plot Group dialog box, type Electric Potential on Electrodes in the New label text field.
- 6 Click OK.
- 7 Click the **x-Axis Log Scale** button in the **Graphics** toolbar.
- 8 In the Electric Potential on Electrodes toolbar, click **OD** Plot.
- 9 In the Model Builder window, collapse the Electric Potential on Electrodes node.

Plot the electron current density on the electrodes as follows:

ID Plot Group 5

In the Home toolbar, click 🚛 Add Plot Group and choose ID Plot Group.

Point Graph 1

- I Right-click ID Plot Group 5 and choose Point Graph.
- 2 In the Settings window for Point Graph, locate the Selection section.
- 3 From the Selection list, choose All boundaries.
- 4 Locate the y-Axis Data section. In the Expression text field, type plas.nJe.
- 5 Locate the Legends section. Select the Show legends check box.
- 6 From the Legends list, choose Manual.
- 7 In the table, enter the following settings:

Legends

Cathode

Anode

8 Locate the Title section. From the Title type list, choose None.

Electron Current Density on Electrodes

- I In the Model Builder window, click ID Plot Group 5.
- 2 In the Settings window for ID Plot Group, locate the Legend section.
- **3** From the **Position** list, choose **Upper left**.
- 4 Right-click ID Plot Group 5 and choose Rename.
- 5 In the **Rename ID Plot Group** dialog box, type Electron Current Density on Electrodes in the **New label** text field.
- 6 Click OK.
- 7 Click the **x-Axis Log Scale** button in the **Graphics** toolbar.

- 8 In the Electron Current Density on Electrodes toolbar, click 🗿 Plot.
- 9 In the Model Builder window, collapse the Electron Current Density on Electrodes node.

Next, plot the secondary electron emission at the cathode.

ID Plot Group 6

In the Home toolbar, click 🔎 Add Plot Group and choose ID Plot Group.

Point Graph 1

- I Right-click ID Plot Group 6 and choose Point Graph.
- **2** Select Boundary 1 only.
- 3 In the Settings window for Point Graph, locate the y-Axis Data section.
- 4 In the **Expression** text field, type plas.sflux.
- 5 Locate the Title section. From the Title type list, choose None.

Secondary Emission Flux

- I In the Model Builder window, right-click ID Plot Group 6 and choose Rename.
- 2 In the Rename ID Plot Group dialog box, type Secondary Emission Flux in the New label text field.
- 3 Click OK.
- 4 In the Model Builder window, collapse the Secondary Emission Flux node.
- **5** Click the **x-Axis Log Scale** button in the **Graphics** toolbar.
- 6 In the Secondary Emission Flux toolbar, click 💽 Plot.

Finally, create a nice plot for the model thumbnail.

Revolution ID I

In the **Results** toolbar, click **More Datasets** and choose **Revolution ID**.

RESULTS

In the Model Builder window, collapse the Results>Datasets node.

2D Plot Group 7

In the **Results** toolbar, click **2D Plot Group**.

Surface 1

- I Right-click 2D Plot Group 7 and choose Surface.
- 2 In the Settings window for Surface, locate the Expression section.
- **3** In the **Expression** text field, type log(plas.ne).

Log of Electron Density

- I In the Model Builder window, right-click 2D Plot Group 7 and choose Rename.
- 2 In the Rename 2D Plot Group dialog box, type Log of Electron Density in the New label text field.
- 3 Click OK.
- 4 In the Model Builder window, collapse the Log of Electron Density node.
- 5 In the Log of Electron Density toolbar, click 💽 Plot.
- 6 Click the **Zoom Extents** button in the **Graphics** toolbar.