

Model created in COMSOL Multiphysics 6.4

DC Glow Discharge, 1D

Introduction

DC glow discharges in the low pressure regime have long been used for gas lasers and fluorescent lamps. DC discharges are good to study because the solution is time independent. This model shows how to use the **Plasma** interface to set up an analysis of a positive column. The discharge is sustained by emission of secondary electrons at the cathode.

Model Definition

The DC discharge consists of two electrodes, one powered (the anode) and one grounded (the cathode):

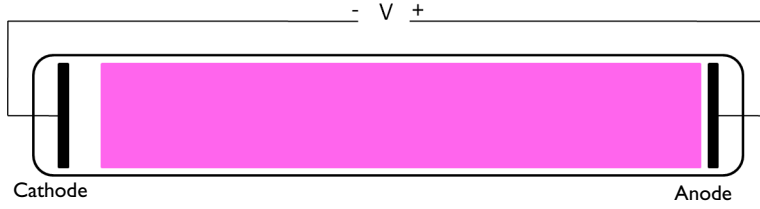


Figure 1: Schematic of the DC discharge. The voltage applied across the electrodes leads to formation of a plasma.

DOMAIN EQUATIONS

Electron transport is modeled by solving the continuity equation, the momentum equation under the drift-diffusion approximation, and the mean electron energy equation (for detailed information on electron transport, see *Theory for the Drift Diffusion Interface* in the *Plasma Module User's Guide*)

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

$$\frac{\partial}{\partial t}(n_\varepsilon) + \nabla \cdot [-n_\varepsilon(\mu_\varepsilon \cdot \mathbf{E}) - \mathbf{D}_\varepsilon \cdot \nabla n_\varepsilon] + \mathbf{E} \cdot \Gamma_e = S_{\text{en}}$$

The source coefficients in the above equations are determined by the plasma chemistry. The electron rate expression is defined as

$$R_e = N_A \sum_j \nu_{e,j} r_j$$

where $\nu_{e,j}$ is the stoichiometric coefficient, and the reaction rate is defined as

$$r_j = k_j^f \prod_{i \in \text{react}} c_i^{-\nu_{i,j}} + k_j^r \prod_{i \in \text{prod}} c_k^{\nu_{i,j}}$$

where k_j^f is the forward rate constant and k_j^r is the reversed rate constant. Both the Electron Impact Reaction feature and Reaction feature can contribute to the electron rate expression. However, when using the Reaction feature it is important to note that the associated electron energy gain or loss is not included in the source term of the electron mean energy equation.

The rate constants can be computed from electron impact cross-section data

$$k^f = N_A \gamma \int_0^\infty \epsilon \sigma(\epsilon) f(\epsilon) d\epsilon$$

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 electron energy (SI unit: V), σ is the electron impact collision cross section (SI unit: m^2), and f is the electron energy distribution function.

When *Townsend coefficients* are used, the reaction rate is defined as

$$r_j = \frac{\alpha_j}{N_n} |\Gamma_e| \prod_{i \neq e \in \text{react}} c_i^{-\nu_{i,j}}$$

where α_j/N_n is the reduced Townsend coefficient for reaction j (SI unit: m^2) and Γ_e is the electron flux as defined above (SI unit: $1/(m^2 \cdot s)$). Townsend coefficients can increase the stability of the numerical scheme when the electron flux is field driven as is the case with DC discharges.

The total electron energy loss or gained is calculated by summing the collisional energy changes from all reactions defined with the Electron Impact Reaction feature as

$$S_{\text{en}} = - \sum_j r_j \Delta \epsilon_j F$$

where $\Delta \epsilon_j$ is the energy loss from reaction j (SI unit: V) and F is the Faraday constant (SI unit: C/mol). For excitation and ionization collisions $\Delta \epsilon_j$ corresponds to the energy of the excited state being excited/deexcited or ionized, for attachment $\Delta \epsilon_j$ is set to zero, and for elastic collisions

$$\Delta \epsilon = 2 \frac{m_e}{m_k} \frac{3}{2} \left[T_e (eV) - \frac{k_B}{e} T_{\text{gas}} (K) \right]$$

where m_e and m_k are the electron and heavy species mass in kg, T_e is the electron temperature in eV, and T_{gas} is the gas temperature in K.

For heavy species, the following equation is solved for the mass fraction of each species (for detailed information on the transport of the nonelectron species, see *Theory for the Heavy Species Transport Interface* in the *Plasma Module User's Guide*):

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

The electrostatic field is computed using the following equation:

$$-\nabla \cdot \epsilon_0 \epsilon_r \nabla V = \rho$$

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

Unlike RF discharges, the mechanism for sustaining the discharge is emission of secondary electrons from the cathode. An electron is emitted from the cathode surface with a specified probability when struck by an ion. These electrons are then accelerated by the strong electric field close to the cathode where they acquire enough energy to initiate ionization. The net result is a rapid increase in the electron density close to the cathode in a region often known as the *cathode fall* or *Crookes dark space*.

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 electron flux boundary condition

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

and the electron energy flux boundary condition

$$\mathbf{n} \cdot \Gamma_\varepsilon = \left(\frac{5}{6}v_{e,th}n_\varepsilon\right) - \sum_p \varepsilon_p \gamma_p (\Gamma_p \cdot \mathbf{n}) \quad (2)$$

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:

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

PLASMA CHEMISTRY

Argon is one of the simplest mechanisms to implement at low pressures. The electronically excited states can be lumped into a single species which results in a chemical mechanism consisting of only 3 species and 7 reactions (electrons impact cross sections are obtained from Ref. 2):

TABLE 1: TABLE OF COLLISIONS AND REACTIONS MODELED.

Reaction	Formula	Type	$\Delta\varepsilon$ (eV)
1	e+Ar=>e+Ar	Elastic	0
2	e+Ar=>e+Ar*	Excitation	11.5
3	e+Ar*=>e+Ar	Superelastic	-11.5
4	e+Ar=>2e+Ar+	Ionization	15.8
5	e+Ar*=>2e+Ar+	Ionization	4.24
6	Ar*+Ar*=>e+Ar+Ar+	Penning ionization	-
7	Ar*+Ar=>Ar+Ar	Metastable quenching	-

In this discharge, the electron density and the density of the excited species are relatively low, so stepwise ionization is not as important as in high density discharges. In addition to volumetric reactions, the following surface reactions are implemented:

TABLE 2: TABLE OF SURFACE REACTIONS.

Reaction	Formula	Sticking coefficient
1	Ar*=>Ar	1
2	Ar+=>Ar	1

When a metastable argon atom makes contact with the wall, it reverts to the ground state argon atom with some probability (the sticking coefficient).

Results and Discussion

The electric potential, electron density, and mean electron energy are all quantities of interest. Most of the variation in each of these quantities occurs along the axial length of the column. [Figure 2](#) plots the electron density in the column. The electron density peaks in the region between the cathode fall and positive column. This region is sometimes referred to as Faraday dark space. The electron density obtained in this 1D model is different than that obtained in the 2D model because the diffusive loss of electrons to the outer walls and the accumulation of surface charge on the walls are not modeled.

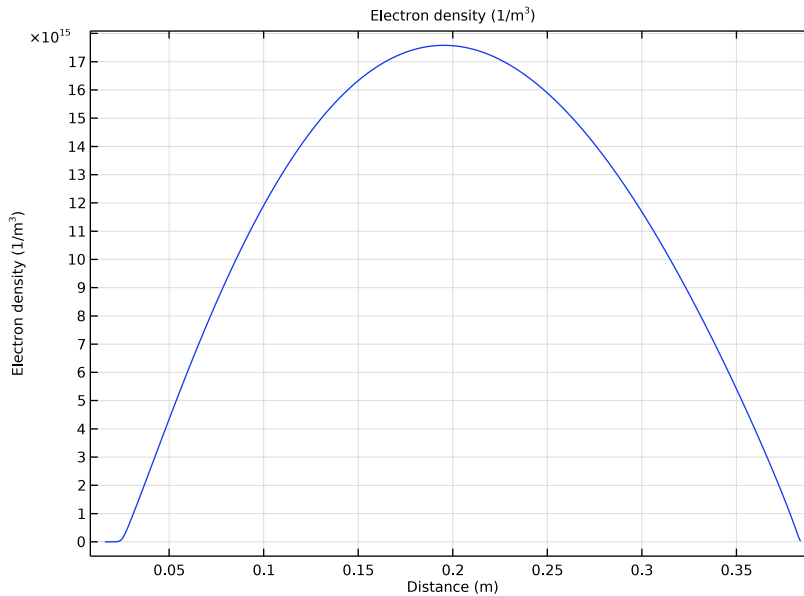


Figure 2: Electron density along the axial length of the positive column.

In [Figure 3](#) the electric potential is plotted along the axial length of the column. Notice that the potential profile is significantly different from the linear drop in potential which results in the absence of the plasma. The strong electric field in the cathode region can lead to high energy ion bombardment of the cathode. Heating of the cathode surface occurs which may in turn lead to thermal electron emission where additional electrons are emitted from the cathode surface.

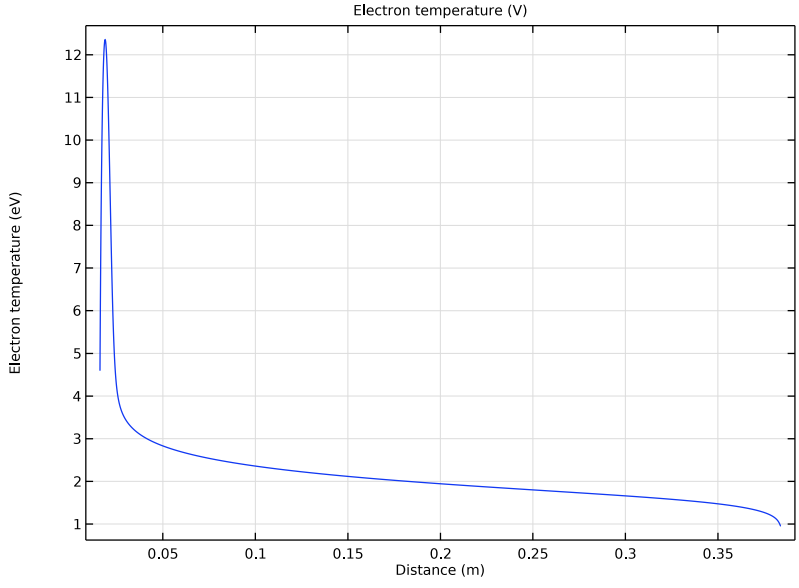


Figure 3: Electron temperature along the axial length of the positive column.

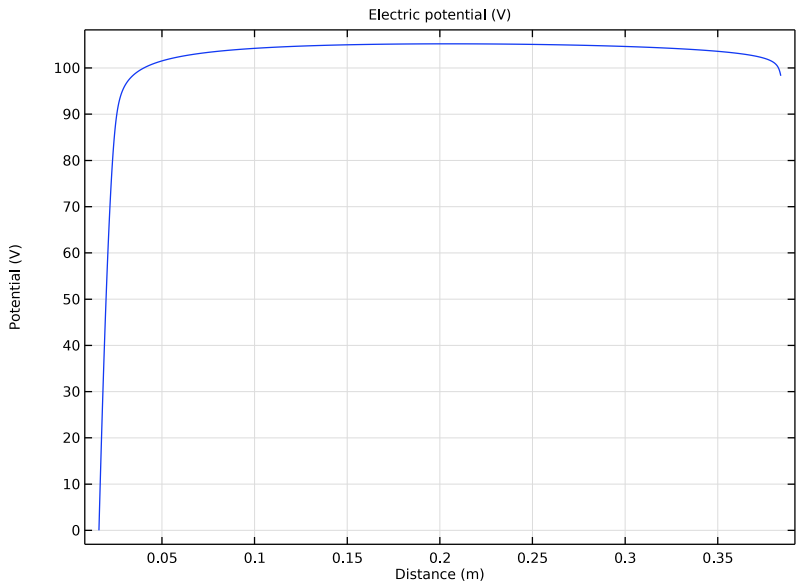


Figure 4: Potential along the axial length of the positive column.

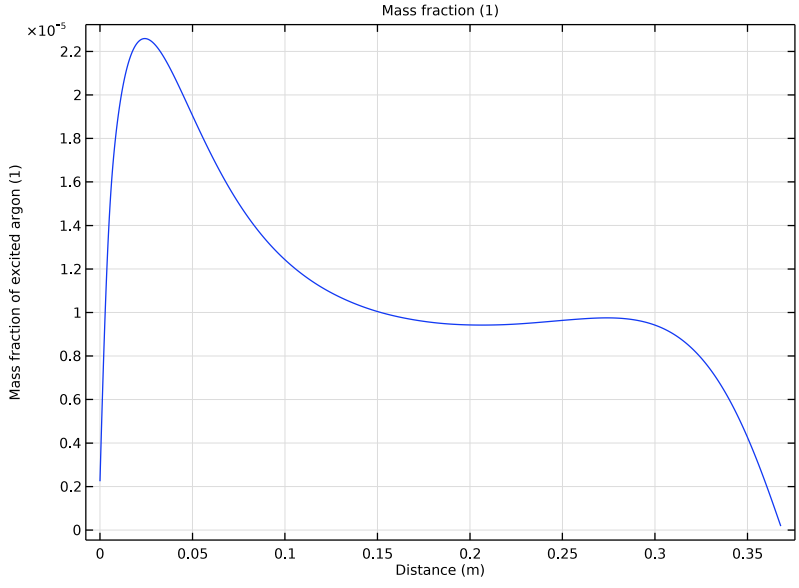


Figure 5: Mass fraction of excited argon atoms along the axial length of the positive column.

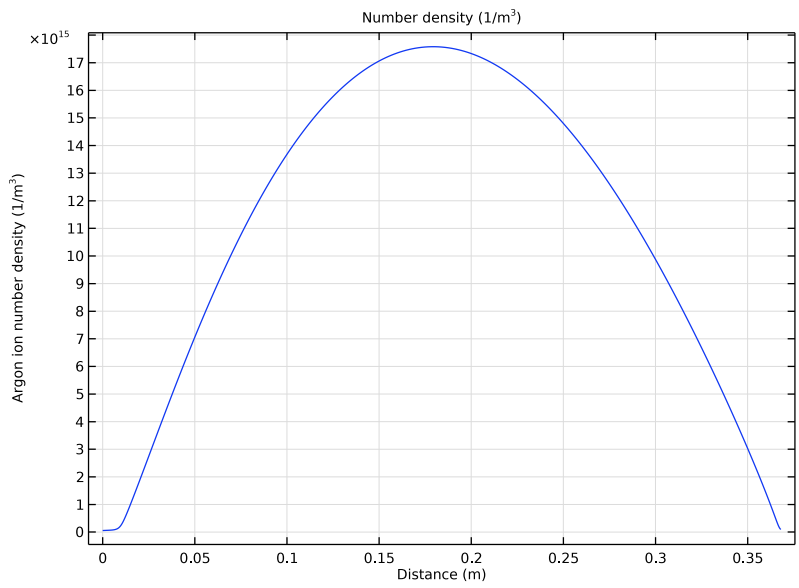


Figure 6: Number density of argon ions along the axial length of the positive column.

The plasma current due to electrons, ions and their sum is plotted in Figure 7. As expected, the ion current is highest at the cathode and increases sharply in the cathode fall region. The ion bombardment of the cathode results in an electron current released from the electrode. The electron current increases sharply in the cathode fall region because the high electron temperature results in production of new electrons which then contribute to the total electron current. Once the electrons pass the cathode fall region, the electron current density further increases due to production of new electrons through electron impact ionization with the background gas.

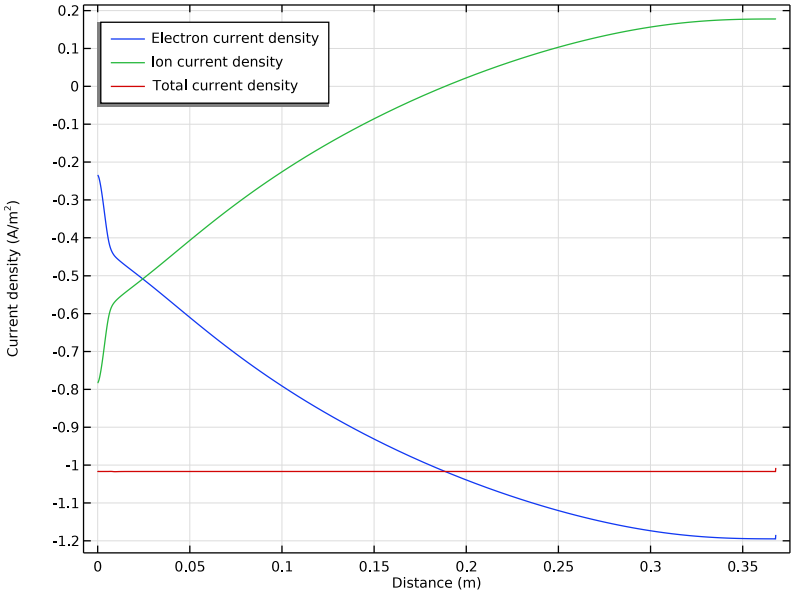


Figure 7: Electron current density (blue), ion current density (green), and total current density (red) along the axial length of the positive column.

References


1. M.A. Lieberman and A.J. Lichtenberg, *Principles of Plasma Discharges and Materials Processing*, John Wiley & Sons, 2005.
2. Phelps database, www.lxcat.net, retrieved 2017.

Application Library path: Plasma_Module/Direct_Current_Discharges/
positive_column_1d




Modeling Instructions

From the **File** menu, choose **New**.

NEW

In the **New** window, click  **Model Wizard**.

MODEL WIZARD

- 1 In the **Model Wizard** window, click  **ID**.
- 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**.

GEOMETRY I

The geometry interval is defined to be consistent with the 2D version of the model, which is available in the **Application Library**.

Interval I (il)

- 1 In the **Model Builder** window, under **Component I (comp1)** right-click **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 (m)

0.016

0.384

DEFINITIONS

Variables I




- 1 In the **Definitions** toolbar, click  **Local Variables**.

- 2 In the **Settings** window for **Variables**, locate the **Variables** section.
- 3 In the table, enter the following settings:

Name	Expression	Unit	Description
mueN	1E24[1/(m*V*s)]	1/(V·m·s)	Electron mobility
V0	200[V]	V	Applied voltage
Wf	5		Surface work function
p0	0.1[torr]	Pa	Gas pressure

PLASMA (PLAS)

Cross Section Import I

- 1 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**.
- 6 In the **Model Builder** window, click **Plasma (plas)**.
- 7 In the **Settings** window for **Plasma**, locate the **Plasma Properties** section.
- 8 Select the **Use reduced electron transport properties** checkbox.

Because you will examine the electron, ion, and net currents flowing in the plasma, raise the element order to 2. The current density is computed from space derivatives of the charge carrying degrees of freedom, so using 2nd order shape functions gives a more accurate value for the current density.

- 9 Click to expand the **Discretization** section. From the **Formulation** list, choose **Finite element, log formulation (quadratic shape function)**.


Plasma Model I

- 1 In the **Model Builder** window, click **Plasma Model I**.
- 2 In the **Settings** window for **Plasma Model**, locate the **Model Inputs** section.
- 3 In the p_A text field, type p0.
- 4 Locate the **Electron Density and Energy** section. In the $\mu_e N_n$ text field, type mueN.


Now change the way the source coefficients for electronic excitation and ionization are specified. By default, COMSOL Multiphysics computes rate coefficients based on the cross section data you supplied. For DC discharges, Townsend coefficients provide a

more accurate description of the cathode fall region so they should be used. The Townsend coefficients are typically computed using the **Boltzmann Equation, Two-Term Approximation** interface.


2: $e+Ar=>e+Ar_s$

- 1 In the **Model Builder** window, click **2: $e+Ar=>e+Ar_s$** .
- 2 In the **Settings** window for **Electron Impact Reaction**, locate the **Collision** section.
- 3 From the **Specify reaction using** list, choose **Use lookup table**.
- 4 Locate the **Reaction Parameters** section. From the **Rate constant form** list, choose **Townsend coefficient**.
- 5 Find the **Townsend coefficient data** subsection. Click  **Load from File**.
- 6 Browse to the model's Application Libraries folder and double-click the file town2.txt.


4: $e+Ar=>2e+Ar+$

- 1 In the **Model Builder** window, click **4: $e+Ar=>2e+Ar+$** .
- 2 In the **Settings** window for **Electron Impact Reaction**, locate the **Collision** section.
- 3 From the **Specify reaction using** list, choose **Use lookup table**.
- 4 Locate the **Reaction Parameters** section. From the **Rate constant form** list, choose **Townsend coefficient**.
- 5 Find the **Townsend coefficient data** subsection. Click  **Load from File**.
- 6 Browse to the model's Application Libraries folder and double-click the file town4.txt.

Reaction 1

- 1 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 $Ar_s+Ar_s=>e+Ar+Ar+$.
- 4 Locate the **Reaction Parameters** section. In the k^f text field, type 3.734E8.

Reaction 2

- 1 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 $Ar_s+Ar=>Ar+Ar$.
- 4 Locate the **Reaction Parameters** section. In the k^f text field, type 1807.

Species: Ar

- 1 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** checkbox.

4 Locate the **General Parameters** section. From the **Preset species data** list, choose **Ar**.

When solving a reacting flow problem there always needs to be one species which is selected to fulfill the mass constraint. This should be taken as the species with the largest mass fraction.

Species: Ars

1 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**.

When solving a plasma problem the plasma must be initially charge neutral. COMSOL automatically computes the initial concentration of a selected ionic species such that the electroneutrality constraint is satisfied.

Species: Ar+

1 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** checkbox.

4 Locate the **General Parameters** section. From the **Preset species data** list, choose **Ar**.

Now add a surface reaction which describes the neutralization of argon ions on the electrode. Secondary emission of electrons is required to sustain the discharge, so enter the emission coefficient and an estimate of the mean energy of the secondary electrons based on the ionization energy threshold and the work function of the surface.

Surface Reaction 1

1 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 $\text{Ar}^+ \Rightarrow \text{Ar}$.

4 Select Boundary 1 only.

Make the secondary emission coefficient 0.35 and set the mean energy of the secondary electrons to be the ionization energy (given by the expression plas.de_4) minus twice the work function of the electrode.

5 Locate the **Secondary Emission Parameters** section. In the γ_i text field, type 0.35.


6 In the ϵ_i text field, type $\text{plas.de}_4 - 2 * \text{Wf}$.

Surface Reaction 2


1 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 $\text{Ar}+\Rightarrow\text{Ar}$.
- 4 Select Boundary 2 only.


Surface Reaction 3

- 1 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 $\text{Ar}_s\Rightarrow\text{Ar}$.
- 4 Click in the **Graphics** window and then press Ctrl+A to select both boundaries.


Wall 1

- 1 In the **Physics** toolbar, click  **Boundaries** and choose **Wall**.
- 2 Click in the **Graphics** window and then press Ctrl+A to select both boundaries.

Ground 1

- 1 In the **Physics** toolbar, click  **Boundaries** and choose **Ground**.
- 2 Select Boundary 1 only.

Metal Contact 1

- 1 In the **Physics** toolbar, click  **Boundaries** and choose **Metal Contact**.
- 2 Select Boundary 2 only.
- 3 In the **Settings** window for **Metal Contact**, locate the **Terminal** section.
- 4 In the V_0 text field, type V_0 .
- 5 Locate the **Circuit Settings** section. From the **Circuit type** list, choose **Ballast resistor**.
- 6 In the R_b text field, type 10000[ohm].


MESH 1

Edge 1

In the **Mesh** toolbar, click  **Edge**.



Distribution 1

- 1 Right-click **Edge 1** 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 200.
- 5 In the **Element ratio** text field, type 50.

- 6 From the **Growth rate** list, choose **Exponential**.
- 7 Select the **Symmetric distribution** checkbox.
- 8 Click  **Build All**.


STUDY 1

Step 1: Time Dependent

- 1 In the **Model Builder** window, under **Study 1** click **Step 1: 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, 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 101.
- 9 From the **Function to apply to all values** list, choose **exp10(x) – Exponential function (base 10)**.
- 10 Click **Add**.
- 11 In the **Study** toolbar, click  **Compute**.


RESULTS

Electron Density (plas)


- 1 In the **Settings** window for **ID Plot Group**, locate the **Data** section.
- 2 From the **Time selection** list, choose **Last**.
- 3 Locate the **Plot Settings** section.
- 4 Select the **x-axis label** checkbox. In the associated text field, type Distance (m).
- 5 Select the **y-axis label** checkbox.
- 6 Click the  **Zoom Extents** button in the **Graphics** toolbar.

Electron Temperature (plas)


- 1 In the **Model Builder** window, click **Electron Temperature (plas)**.
- 2 In the **Settings** window for **ID Plot Group**, locate the **Data** section.
- 3 From the **Time selection** list, choose **Last**.
- 4 Locate the **Plot Settings** section.

- 5 Select the **x-axis label** checkbox. In the associated text field, type Distance (m).
- 6 Select the **y-axis label** checkbox. In the associated text field, type Electron temperature (eV).
- 7 Click the  **Zoom Extents** button in the **Graphics** toolbar.


Electric Potential (plas)

- 1 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**.
- 4 Locate the **Plot Settings** section.
- 5 Select the **x-axis label** checkbox. In the associated text field, type Distance (m).
- 6 Select the **y-axis label** checkbox. In the associated text field, type Potential (V).
- 7 Click the  **Zoom Extents** button in the **Graphics** toolbar.


Excited Argon Mass Fraction

- 1 In the **Results** toolbar, click  **ID Plot Group**.
- 2 In the **Settings** window for **ID Plot Group**, type Excited Argon Mass Fraction in the **Label** text field.
- 3 Locate the **Data** section. From the **Time selection** list, choose **Last**.
- 4 Locate the **Plot Settings** section.
- 5 Select the **x-axis label** checkbox. In the associated text field, type Distance (m).
- 6 Select the **y-axis label** checkbox. In the associated text field, type Mass fraction of excited argon (1).

Line Graph 1


- 1 Right-click **Excited Argon Mass Fraction** and choose **Line Graph**.
- 2 Select Domain 1 only.
- 3 In the **Settings** window for **Line Graph**, click **Replace Expression** in the upper-right corner of the **y-Axis Data** section. From the menu, choose **Component 1 (comp1) > Plasma > Mass fractions > plas.wArs - Mass fraction - I**.
- 4 In the **Excited Argon Mass Fraction** toolbar, click  **Plot**.

Argon Ion Number Density

- 1 In the **Results** toolbar, click  **ID Plot Group**.
- 2 In the **Settings** window for **ID Plot Group**, type Argon Ion Number Density in the **Label** text field.

- 3 Locate the **Data** section. From the **Time selection** list, choose **Last**.
- 4 Locate the **Plot Settings** section.
- 5 Select the **x-axis label** checkbox. In the associated text field, type Distance (m).
- 6 Select the **y-axis label** checkbox. In the associated text field, type Argon ion number density ($1/m^{3}$).


Line Graph I

- 1 Right-click **Argon Ion Number Density** and choose **Line Graph**.
- 2 Select Domain I only.
- 3 In the **Settings** window for **Line Graph**, click **Replace Expression** in the upper-right corner of the **y-Axis Data** section. From the menu, choose **Component I (comp1) > Plasma > Number densities > plas.n_wAr_1p - Number density - $1/m^3$** .
- 4 In the **Argon Ion Number Density** toolbar, click  **Plot**.

Current Density

- 1 In the **Model Builder** window, right-click **Argon Ion Number Density** and choose **Duplicate**.
- 2 In the **Settings** window for **ID Plot Group**, type Current Density in the **Label** text field.
- 3 Click to expand the **Title** section. From the **Title type** list, choose **None**.
- 4 Locate the **Plot Settings** section. In the **y-axis label** text field, type Current density (A/m^2).
- 5 Locate the **Legend** section. From the **Position** list, choose **Upper left**.

Line Graph I


- 1 In the **Model Builder** window, expand the **Current Density** node, then click **Line Graph I**.
- 2 In the **Settings** window for **Line Graph**, click **Replace Expression** in the upper-right corner of the **y-Axis Data** section. From the menu, choose **Component I (comp1) > Plasma > Current > Electron current density - A/m^2 > plas.Jelx - Electron current density, x-component**.
- 3 Click to expand the **Quality** section. From the **Evaluation settings** list, choose **Manual**.
- 4 From the **Resolution** list, choose **No refinement**.
- 5 From the **Recover** list, choose **Within domains**.
- 6 Click to expand the **Legends** section. Select the **Show legends** checkbox.
- 7 From the **Legends** list, choose **Manual**.
- 8 In the **Current Density** toolbar, click  **Plot**.

9 In the table, enter the following settings:

Legends

Electron current density

Line Graph 2

- 1 Right-click **Results > Current Density > Line Graph 1** and choose **Duplicate**.
- 2 In the **Settings** window for **Line Graph**, click **Replace Expression** in the upper-right corner of the **y-Axis Data** section. From the menu, choose **Component 1 (comp1) > Plasma > Species > Species wAr_1p > Ion current density - A/m² > plas.Jix_wAr_1p - Ion current density, x-component**.
- 3 In the **Current Density** toolbar, click  **Plot**.
- 4 Locate the **Legends** section. In the table, enter the following settings:

Legends


Ion current density

Line Graph 3

- 1 Right-click **Line Graph 1** and choose **Duplicate**.
- 2 In the **Settings** window for **Line Graph**, locate the **y-Axis Data** section.
- 3 In the **Expression** text field, type `plas.Jix_wAr_1p+plas.Jelx`.
- 4 Locate the **Legends** section. In the table, enter the following settings:

Legends

Total current density

- 5 In the **Current Density** toolbar, click  **Plot**.