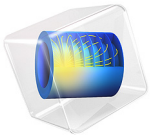


DC Glow Discharge

Introduction

DC glow discharges in the low-pressure regime have long been used for gas lasers and fluorescent lamps. DC discharges are attractive 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). The positive column is coupled to an external circuit:

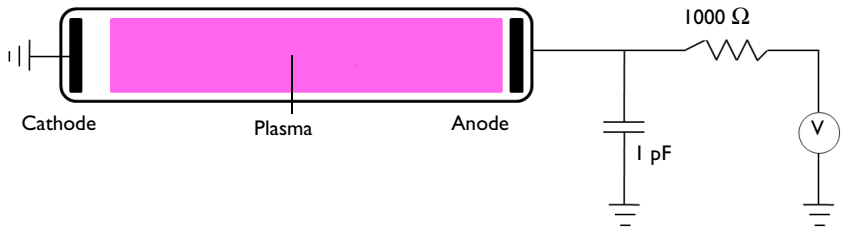


Figure 1: Schematic of the DC discharge and external circuit.

DOMAIN EQUATIONS

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

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

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

where:

$$\Gamma_e = -(\mu_e \bullet \mathbf{E})n_e - \mathbf{D}_e \bullet \nabla n_e$$

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:

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

The source coefficients in the above equations are determined by the plasma chemistry using rate coefficients. Suppose that there are M reactions which contribute to the growth or decay of electron density and P inelastic electron-neutral collisions. In general $P >> M$. 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 (m^3/s), and N_n is the total neutral number density ($1/m^3$). For DC discharges it is better practice to use Townsend coefficients instead of rate coefficients to define reaction rates. Townsend coefficients provide a better description of what happens in the cathode fall region Ref 1. When Townsend coefficients are used, the electron source term is given by:

$$R_e = \sum_{j=1}^{M} x_j \alpha_j N_n |\Gamma_e|$$

where α_j is the Townsend coefficient for reaction j (m^2) and Γ_e is the electron flux as defined above ($1/(m^2 \cdot s)$). 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 electron energy loss is obtained by summing the collisional energy loss over all reactions:

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

where $\Delta\varepsilon_j$ is the energy loss from reaction j (V). The rate coefficients may be computed from cross section data by the following integral:

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

where $\gamma = (2q/m_e)^{1/2}$ ($C^{1/2}/kg^{1/2}$), m_e is the electron mass (kg), ε is energy (V), σ_k is the collision cross section (m^2) and f is the electron energy distribution function. In this case a Maxwellian EEDF is assumed. When Townsend coefficients are used, the electron energy loss is taken as:

$$R_\varepsilon = \sum_{j=1}^{P} x_j \alpha_j N_n |\Gamma_e| \Delta\varepsilon_j$$

For non-electron species, the following equation is solved for the mass fraction of each species. For detailed information on the transport of the non-electron 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:

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

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

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 following boundary condition for the electron flux:

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

and the electron energy flux:

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

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 (electron impact cross-sections are obtained form 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+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	Ars+Ars=>e+Ar+Ar+	Penning ionization	-
7	Ars+Ar=>Ar+Ar	Metastable quenching	-

In this discharge, the electron density and density of excited species is 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	Ars=>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 also decreases rapidly in the radial direction. The is caused by diffusive loss of electrons to the outer walls of the column where they accumulate a surface charge. The buildup of negative charge leads to a positive potential in the center of the column with respect to the walls.

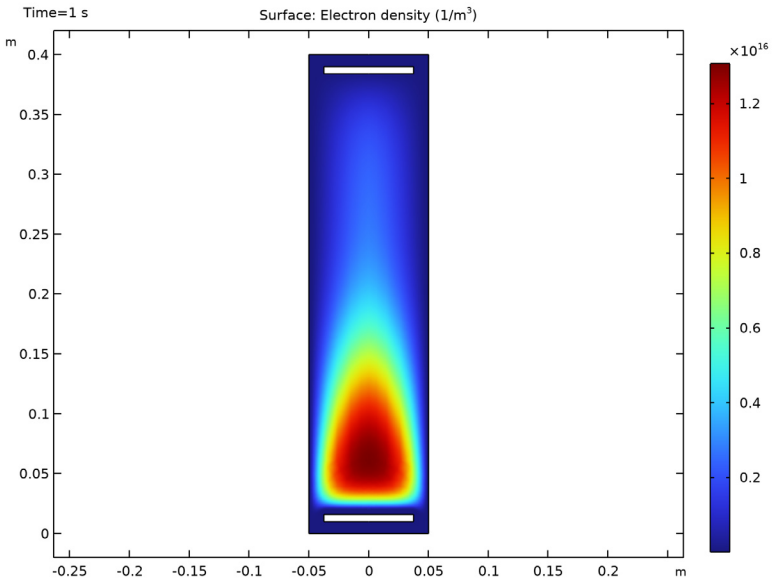


Figure 2: Surface plot of electron density inside the column.

In Figure 4 the electric potential is plotted along the axial length of the column. Notice that the potential profile is markedly 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.

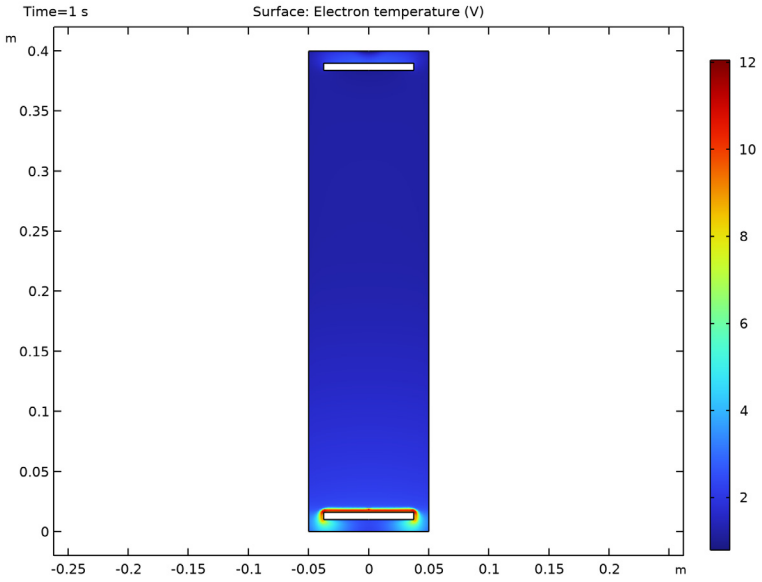


Figure 3: Plot of electron "temperature" along the axial length of the positive column.

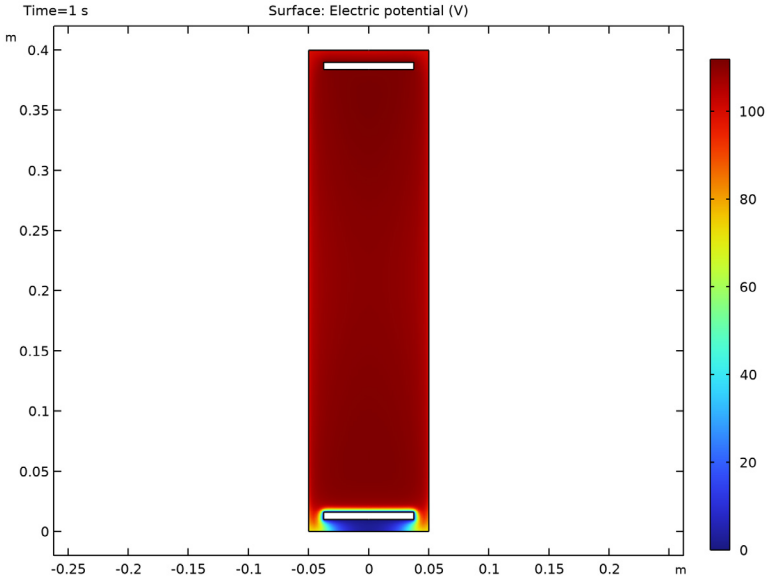


Figure 4: Plot of the electric potential along the axial length of the positive column.

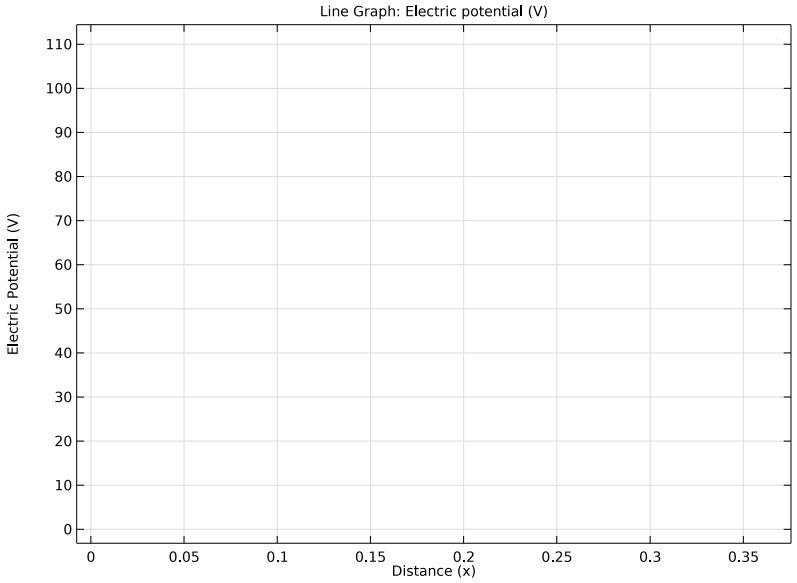


Figure 5: Plot of electric potential along the axial length of the positive column.

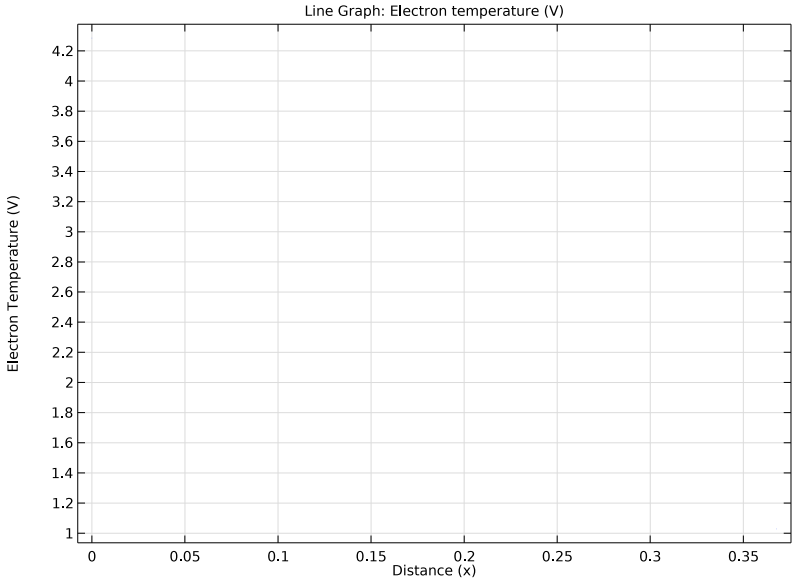


Figure 6: Plot of the electron temperature along the axial length of the positive column.

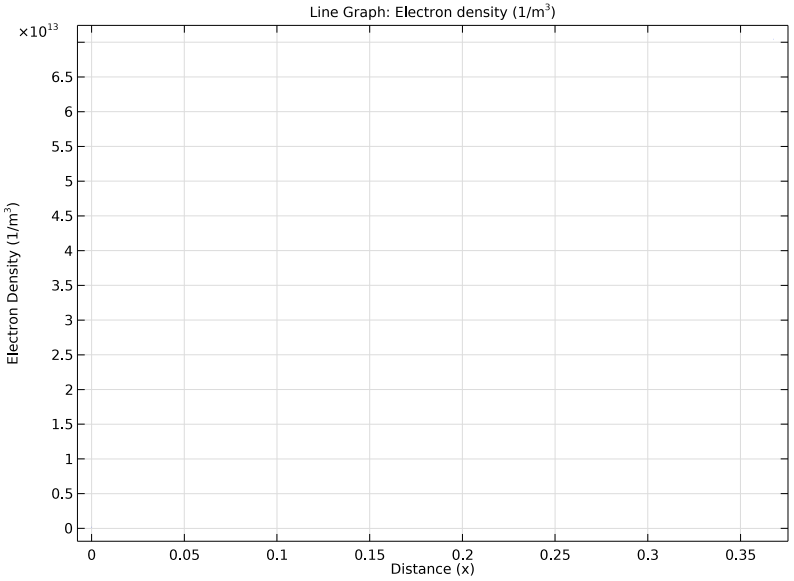


Figure 7: Plot of the electron density along the axial length of the positive column.

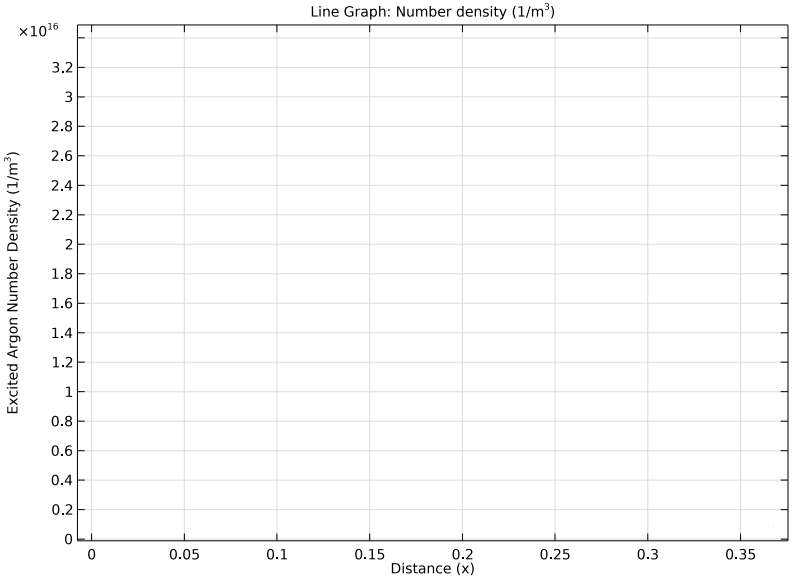


Figure 8: Plot of the number density of excited argon atoms.

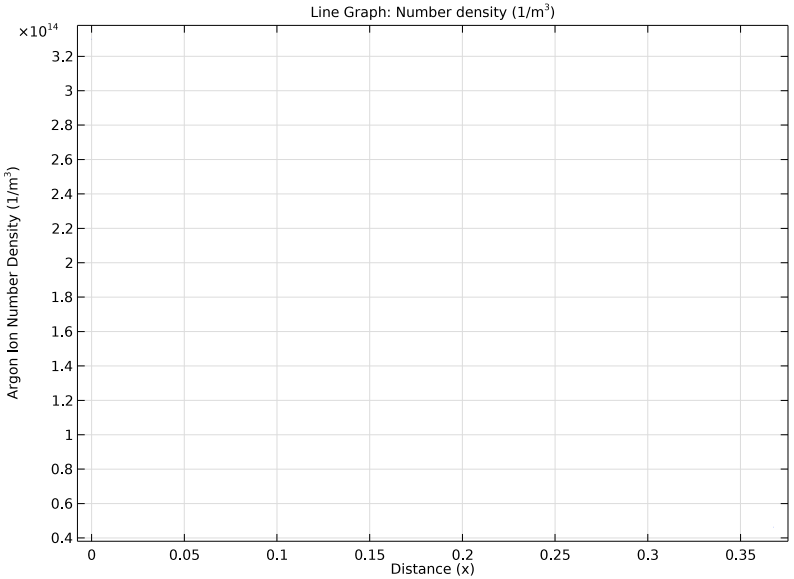


Figure 9: Plot of the number density of argon ions.

Reference

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_2d`

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 **2D 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**.

GEOMETRY 1

Rectangle 1 (r1)

1 In the **Geometry** toolbar, click **Rectangle**.

2 In the **Settings** window for **Rectangle**, locate the **Size and Shape** section.

3 In the **Width** text field, type `0.05`.

4 In the **Height** text field, type `0.4`.

Rectangle 2 (r2)

1 In the **Geometry** toolbar, click **Rectangle**.

2 In the **Settings** window for **Rectangle**, locate the **Size and Shape** section.

3 In the **Width** text field, type `0.0375`.

4 In the **Height** text field, type `6e-3`.

5 Locate the **Position** section. In the **z** text field, type `0.01`.

Rectangle 3 (r3)

1 In the **Geometry** toolbar, click **Rectangle**.

2 In the **Settings** window for **Rectangle**, locate the **Size and Shape** section.

3 In the **Width** text field, type `0.0375`.

4 In the **Height** text field, type `6e-3`.

5 Locate the **Position** section. In the **z** text field, type `0.384`.

Compose 1 (co1)

1 In the **Geometry** toolbar, click **Booleans and Partitions** and choose **Compose**.

2 Select the object **r1** only.

3 In the **Settings** window for **Compose**, locate the **Compose** section.

4 In the **Set formula** text field, type `r1-r2-r3`.

Line Segment 1 (ls1)

1 In the **Geometry** toolbar, click **More Primitives** and choose **Line Segment**.

2 In the **Settings** window for **Line Segment**, locate the **Starting Point** section.

3 From the **Specify** list, choose **Coordinates**.

4 Locate the **Endpoint** section. From the **Specify** list, choose **Coordinates**.

5 Locate the **Starting Point** section. In the **z** text field, type `0.02`.

6 Locate the **Endpoint** section. In the **r** text field, type `0.0375`.

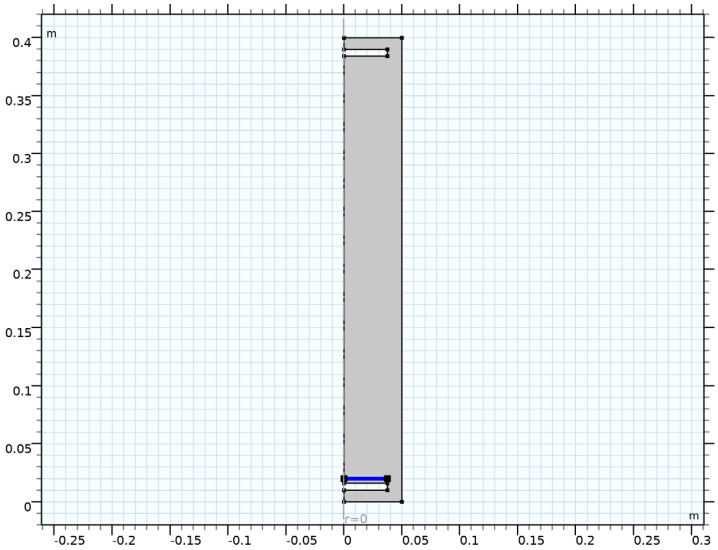
7 In the **z** text field, type `0.02`.

8 Click **Build All Objects**.

Mesh Control Edges 1 (mce1)

1 In the **Geometry** toolbar, click **Virtual Operations** and choose **Mesh Control Edges**.

2 On the object **fin**, select Boundary 7 only.



3 In the **Geometry** toolbar, click **Build All**.

DEFINITIONS

Variables 1

1 In the **Home** toolbar, click **Variables** and choose **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	1E25[1/(m*V*s)]	1/(V·m·s)	Reduced electron mobility
V0	125[V]	V	Applied voltage
Wf	5		Work function
p0	0.5[torr]	Pa	Gas pressure

Cathode

1 In the **Definitions** toolbar, click **Explicit**.

2 Right-click **Explicit 1** and choose **Rename**.

3 In the **Rename Explicit** dialog box, type `Cathode` in the **New label** text field.

4 Click **OK**.

5 In the **Settings** window for **Explicit**, locate the **Input Entities** section.

6 From the **Geometric entity level** list, choose **Boundary**.

7 Select Boundaries 3, 5, and 10 only.

Anode

1 In the **Definitions** toolbar, click **Explicit**.

2 In the **Model Builder** window, right-click **Explicit 2** and choose **Rename**.

3 In the **Rename Explicit** dialog box, type `Anode` in the **New label** text field.

4 Click **OK**.

5 In the **Settings** window for **Explicit**, locate the **Input Entities** section.

6 From the **Geometric entity level** list, choose **Boundary**.

7 Select Boundaries 6, 8, and 11 only.

Walls

1 In the **Definitions** toolbar, click **Explicit**.

2 Right-click **Explicit 3** and choose **Rename**.

3 In the **Rename Explicit** dialog box, type `Walls` in the **New label** text field.

4 Click **OK**.

5 In the **Settings** window for **Explicit**, locate the **Input Entities** section.

6 From the **Geometric entity level** list, choose **Boundary**.

7 Select Boundaries 2, 9, and 12 only.

All Walls

1 In the **Definitions** toolbar, click **Explicit**.

2 In the **Model Builder** window, right-click **Explicit 4** and choose **Rename**.

3 In the **Rename Explicit** dialog box, type `All Walls` in the **New label** text field.

4 Click **OK**.

5 In the **Settings** window for **Explicit**, locate the **Input Entities** section.

6 From the **Geometric entity level** list, choose **Boundary**.

7 Select Boundaries 2, 3, 5, 6, and 8–12 only.

Non Cathode Walls

1 In the **Definitions** toolbar, click **Explicit**.

2 Right-click **Explicit 5** and choose **Rename**.

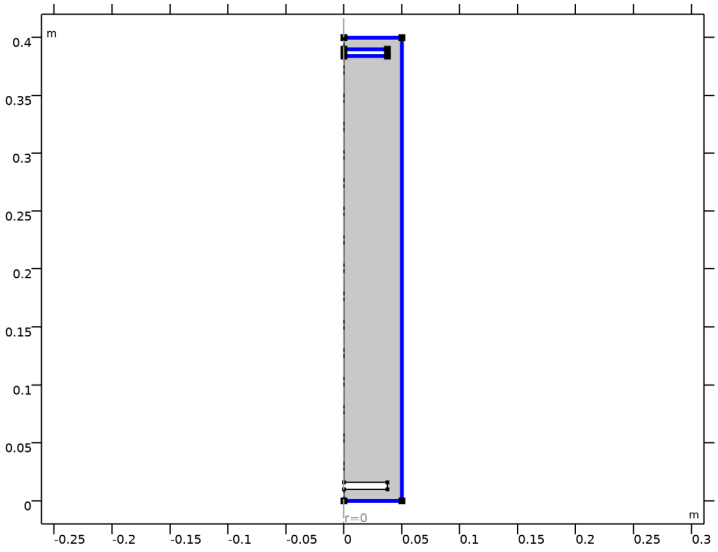
3 In the **Rename Explicit** dialog box, type `Non Cathode Walls` in the **New label** text field.

4 Click **OK**.

5 In the **Settings** window for **Explicit**, locate the **Input Entities** section.

6 From the **Geometric entity level** list, choose **Boundary**.

7 Select Boundaries 2, 6, 8, 9, 11, and 12 only.



Cross Section Import 1

1 In the **Model Builder** window, under **Component 1 (comp1)** right-click **Plasma (plas)** and choose **Global>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** check box.

Plasma Model 1

1 In the **Model Builder** window, click **Plasma Model 1**.

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`.

You change the way the source coefficients for electronic excitation and ionization are specified. By default, COMSOL 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+Ars

1 In the **Model Builder** window, click **2: e+Ar=>e+Ars**.

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 `Ars+Ars=>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 `Ars+Ar=>Ar+Ar`.

4 Locate the **Reaction Parameters** section. In the k^{f} text field, type `1807`.

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: 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** check box.

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

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** check box.

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

Wall 1

1 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 Walls**.

Ground 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Ground**.

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

3 From the **Selection** list, choose **Cathode**.

Metal Contact 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Metal Contact**.

2 In the **Settings** window for **Metal Contact**, locate the **Boundary Selection** section.

3 From the **Selection** list, choose **Anode**.

4 Locate the **Terminal** section. In the V_0 text field, type `V0`.

5 Locate the **Circuit Settings** section. From the **Circuit type** list, choose **Series RC circuit**.

Dielectric Contact 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Dielectric Contact**.

2 In the **Settings** window for **Dielectric Contact**, locate the **Boundary Selection** section.

3 From the **Selection** list, choose **Walls**.

Now you 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 you 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 `Ar+=>Ar`.

4 Locate the **Boundary Selection** section. From the **Selection** list, choose **Cathode**.

Make the secondary emission coefficient 0.25 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 `0.25`.

6 In the ε_i text field, type `plas.de_4-2*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 `Ar+=>Ar`.

4 Locate the **Boundary Selection** section. From the **Selection** list, choose **Non Cathode Walls**.

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 `Ars=>Ar`.

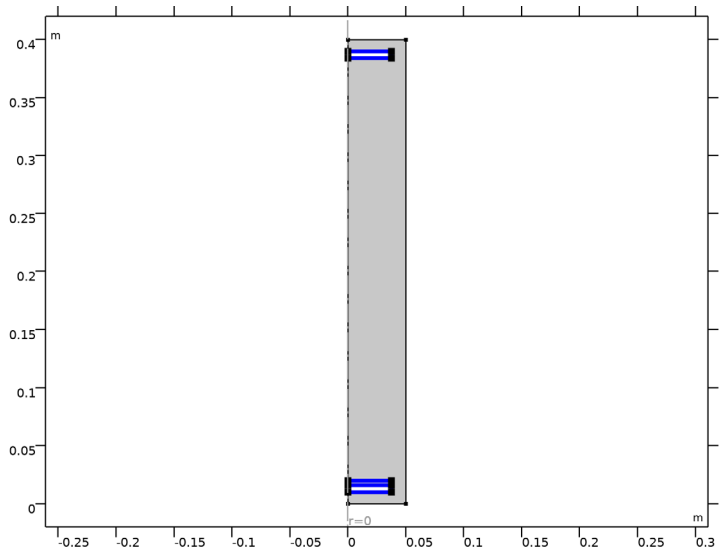
4 Locate the **Boundary Selection** section. From the **Selection** list, choose **All Walls**.

MESH 1

Edge 1

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

2 Select Boundaries 3, 5, 6, 8, 10, 11, and 14 only.



Size 1

1 Right-click **Edge 1** and choose **Size**.

2 In the **Settings** window for **Size**, locate the **Element Size** section.

3 From the **Predefined** list, choose **Extremely fine**.

4 Click the **Custom** button.

5 Locate the **Element Size Parameters** section. Select the **Maximum element size** check box.

6 In the associated text field, type `0.001`.

7 Click the **Zoom Extents** button in the **Graphics** toolbar.

Free Triangular 1

In the **Mesh** toolbar, click **Free Triangular**.

Size 1

1 Right-click **Free Triangular 1** and choose **Size**.

2 In the **Settings** window for **Size**, locate the **Element Size** section.

3 From the **Predefined** list, choose **Extra fine**.

Boundary Layers 1

In the **Mesh** toolbar, click **Boundary Layers**.

Boundary Layer Properties

1 In the **Model Builder** window, click **Boundary Layer Properties**.

2 In the **Settings** window for **Boundary Layer Properties**, locate the **Boundary Selection** section.

3 From the **Selection** list, choose **All Walls**.

4 Locate the **Layers** section. In the **Number of layers** text field, type 4.

5 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 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 21.

9 From the **Function to apply to all values** list, choose **exp10(x)** – **Exponential function (base 10)**.

10 Click **Add**.

11 In the **Home** toolbar, click **Compute**.

RESULTS

Study 1/Solution 1 (sol1)

In the **Model Builder** window, expand the **Results>Datasets** node, then click **Study 1/ Solution 1 (sol1)**.

Selection

1 In the **Results** toolbar, click **Attributes** and choose **Selection**.

2 In the **Settings** window for **Selection**, locate the **Geometric Entity Selection** section.

3 From the **Geometric entity level** list, choose **Boundary**.

4 From the **Selection** list, choose **All Walls**.

Cut Line 2D 1

1 In the **Results** toolbar, click **Cut Line 2D**.

2 In the **Settings** window for **Cut Line 2D**, locate the **Line Data** section.

3 In row **Point 1**, set **Z** to `0.016`.

4 In row **Point 2**, set **R** to `0` and **z** to `0.384`.

Mirror 2D 1

In the **Results** toolbar, click **More Datasets** and choose **Mirror 2D**.

Electron Density (plas)

1 In the **Model Builder** window, under **Results** click **Electron Density (plas)**.

2 In the **Settings** window for **2D Plot Group**, locate the **Data** section.

3 From the **Dataset** list, choose **Mirror 2D 1**.

4 In the **Electron Density (plas)** toolbar, click **Plot**.

5 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 **2D Plot Group**, locate the **Data** section.

3 From the **Dataset** list, choose **Mirror 2D 1**.

4 In the **Electron Temperature (plas)** toolbar, click **Plot**.

5 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 **2D Plot Group**, locate the **Data** section.

3 From the **Dataset** list, choose **Mirror 2D 1**.

4 In the **Electric Potential (plas)** toolbar, click **Plot**.

5 Click the **Zoom Extents** button in the **Graphics** toolbar.

Electric Potential on Axis

1 In the **Home** toolbar, click **Add Plot Group** and choose **1D Plot Group**.

2 In the **Settings** window for **1D Plot Group**, type `Electric Potential on Axis` in the **Label** text field.

3 Locate the **Data** section. From the **Time selection** list, choose **Last**.

4 Locate the **Plot Settings** section. Select the **x-axis label** check box.

5 In the associated text field, type `Distance (x)`.

6 Select the **y-axis label** check box.

7 In the associated text field, type `Electric Potential (V)`.

8 Locate the **Data** section. From the **Dataset** list, choose **Cut Line 2D 1**.

Line Graph 1

1 Right-click **Electric Potential on Axis** and choose **Line Graph**.

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> Electric>V - Electric potential - V**.

Electric Potential on Axis

1 In the **Model Builder** window, click **Electric Potential on Axis**.

2 In the **Electric Potential on Axis** toolbar, click **Plot**.

3 Click the **Zoom Extents** button in the **Graphics** toolbar.

Electron Temperature on Axis

1 In the **Home** toolbar, click **Add Plot Group** and choose **1D Plot Group**.

2 In the **Settings** window for **1D Plot Group**, type `Electron Temperature on Axis` in the **Label** text field.

3 Locate the **Data** section. From the **Time selection** list, choose **Last**.

4 Locate the **Plot Settings** section. Select the **x-axis label** check box.

5 In the associated text field, type `Distance (x)`.

6 Select the **y-axis label** check box.

7 In the associated text field, type `Electron Temperature (V)`.

8 Locate the **Data** section. From the **Dataset** list, choose **Cut Line 2D 1**.

Line Graph 1

1 Right-click **Electron Temperature on Axis** and choose **Line Graph**.

2 In the **Settings** window for **Line Graph**, locate the **y-Axis Data** section.

3 In the **Expression** text field, type `plas.Te`.

4 In the **Electron Temperature on Axis** toolbar, click **Plot**.

5 Click the **Zoom Extents** button in the **Graphics** toolbar.

Electron Density on Axis

1 In the **Home** toolbar, click **Add Plot Group** and choose **1D Plot Group**.

2 In the **Settings** window for **1D Plot Group**, type `Electron Density on Axis` in the **Label** text field.

3 Locate the **Data** section. From the **Time selection** list, choose **Last**.

4 Locate the **Plot Settings** section. Select the **x-axis label** check box.

5 In the associated text field, type `Distance (x)`.

6 Select the **y-axis label** check box.

7 In the associated text field, type `Electron Density (1/m<sup>3</sup>)`.

8 Locate the **Data** section. From the **Dataset** list, choose **Cut Line 2D 1**.

Line Graph 1

1 Right-click **Electron Density on Axis** and choose **Line Graph**.

2 In the **Settings** window for **Line Graph**, locate the **y-Axis Data** section.

3 In the **Expression** text field, type `plas.ne`.

4 In the **Electron Density on Axis** toolbar, click **Plot**.

5 Click the **Zoom Extents** button in the **Graphics** toolbar.

Excited Argon Number Density on Axis

1 In the **Home** toolbar, click **Add Plot Group** and choose **1D Plot Group**.

2 In the **Settings** window for **1D Plot Group**, type `Excited Argon Number Density on Axis` in the **Label** text field.

3 Locate the **Data** section. From the **Time selection** list, choose **Last**.

4 Locate the **Plot Settings** section. Select the **x-axis label** check box.

5 In the associated text field, type `Distance (x)`.

6 Select the **y-axis label** check box.

7 In the associated text field, type `Excited Argon Number Density (1/m<sup>3</sup>)`.

8 Locate the **Data** section. From the **Dataset** list, choose **Cut Line 2D 1**.

Line Graph 1

1 Right-click **Excited Argon Number Density on Axis** and choose **Line Graph**.

2 In the **Settings** window for **Line Graph**, locate the **y-Axis Data** section.

3 In the **Expression** text field, type `plas.n_wArs`.

4 In the **Excited Argon Number Density on Axis** toolbar, click **Plot**.

5 Click the **Zoom Extents** button in the **Graphics** toolbar.

Argon Ion Number Density on Axis

1. In the **Home** toolbar, click  **Add Plot Group** and choose **1D Plot Group**.
2. In the **Settings** window for **1D Plot Group**, type `Argon Ion Number Density on Axis` in the **Label** text field.
3. Locate the **Data** section. From the **Time selection** list, choose **Last**.
4. Locate the **Plot Settings** section. Select the **x-axis label** check box.
5. In the associated text field, type `Distance (x)`.
6. Select the **y-axis label** check box.
7. In the associated text field, type `Argon Ion Number Density (1/m<sup>3</sup>)`.
8. Locate the **Data** section. From the **Dataset** list, choose **Cut Line 2D 1**.

Line Graph 1

1. Right-click **Argon Ion Number Density on Axis** and choose **Line Graph**.
2. In the **Settings** window for **Line Graph**, locate the **y-Axis Data** section.
3. In the **Expression** text field, type `plas.n_wAr_1p`.
4. In the **Argon Ion Number Density on Axis** toolbar, click  **Plot**.
5. Click the  **Zoom Extents** button in the **Graphics** toolbar.