Model created in COMSOL Multiphysics 6.4

Positive Glow Corona Discharge

Introduction

Corona discharges, a prevalent occurrence in both industrial processes and natural phenomena, arise when high voltages are applied to pointed electrodes. These electrodes generate intense electric fields that ionize surrounding gases without causing a complete breakdown across the gap. Typically confined to a localized area, corona discharges manifest as a uniform glow. The characteristics of stable glow corona discharges vary depending on polarity. Positive glow corona, also known as Hermstein's glow or ultra corona, exhibits a direct current (DC) component overlaid with stable current pulses.

This case study investigates a positive glow corona between coaxial cylindrical electrodes. The electric field dynamics and the concentration of charged particles are determined. The total discharge current, alongside the electronic and ionic current constituents, is computed. The simulated electric field, discharge current, and charge-carrier density are in good agreement with those published in Ref. 1.

Model Definition

The Electric Discharge interface is used to simulate the positive corona. The built-in charge transport model is used:

$$\frac{\partial n_i}{\partial t} + \nabla \cdot (\mathbf{w}_i n_i - D_i \nabla n_i) = R_i$$

where

$i = \mathrm{e, p, n}$

$z_{\mathrm{e, p, n}} = -1, +1, -1$

$\mathbf{w}_i = z_i \mu_i \mathbf{E}$

$R_\mathrm{e} = \alpha|\mathbf{w}_\mathrm{e}|n_\mathrm{e} - \eta|\mathbf{w}_\mathrm{e}|n_\mathrm{e} - \beta_\mathrm{ep} n_\mathrm{e} n_\mathrm{p}$

$R_\mathrm{p} = \alpha|\mathbf{w}_\mathrm{e}|n_\mathrm{e} - \beta_\mathrm{ep} n_\mathrm{e} n_\mathrm{p} - \beta_\mathrm{pn} n_\mathrm{p} n_\mathrm{n}$

$R_\mathrm{n} = \eta|\mathbf{w}_\mathrm{e}|n_\mathrm{e} - \beta_\mathrm{pn} n_\mathrm{p} n_\mathrm{n}$

where

- e, p, n denote electrons, positive ions, and negative ions
- n_i is the number density of the charge carrier (SI unit: $1/\mathrm{m}^3$)
- $\mathbf{E}$ is the electric field (SI unit: V/m)
- z_i denotes the carrier charge (SI unit: 1)
- μ_i denotes the carrier mobility (SI unit: $\mathrm{m}^2/(\mathrm{V \cdot s})$)
- $\mathbf{w}_i$ is the drift velocity in the electric field (SI unit: m/s)
- D_i is the diffusion coefficient (SI unit: m^2/s)
- R_i is the reaction rate (SI unit: $1/(\mathrm{m}^3 \cdot \mathrm{s})$)
- α is the ionization coefficient (SI unit: 1/m)
- η is the attachment coefficient (SI unit: 1/m)
- β_ep is the electron–ion recombination coefficient (SI unit: m^3/s)
- β_pn is the ion–ion recombination coefficient (SI unit: m^3/s)

The above transport equations are fully coupled with Poisson's equation through the electric field and the space charge:

$$\nabla \cdot (\varepsilon_\mathrm{r} \varepsilon_0 \mathbf{E}) = \rho$$

$$\rho = e \sum_i z_i n_i$$

where e is the elementary charge.

For atmospheric pressure positive discharges, photoionization is critical. This model uses the radiative transfer model for computing photoionization. See *Photoionization* in the *Electric Discharge Module User's Guide* for further details.

$$\nabla^2 S_{\mathrm{ph}}{}^j - (\lambda_j p_p)^2 S_{\mathrm{ph}}{}^j = -A_j p_p^2 I_{\mathrm{ph}}$$

where

$$j = 1, 2, 3, \ldots$$

$$S_{\mathrm{ph}} = \sum_j S_{\mathrm{ph}}{}^j$$

$$I_{\mathrm{ph}} = \frac{p_q}{p + p_q} \xi \frac{\nu_u}{\nu_i} S_{\mathrm{ion}}$$

where

- $S_{\mathrm{ph}}{}^j$ denotes j^{th} photoionization rate component (SI unit: $1/(\mathrm{m}^3 \cdot \mathrm{s})$)
- p_p is the partial pressure (default value: 150 Torr)
- p is the gas pressure (default value: 760 Torr)
- p_q is the quenching pressure (default value: 30 Torr)
- $\xi \nu_u / \nu_i$ is the photoionization parameter (default value: 0.06)
- A_j and λ_j are fitting parameter
- I_{ph} is the effective ionization intensity (SI unit: $1/(\mathrm{m}^3 \cdot \mathrm{s})$)
- S_{ion} is the impact ionization rate (SI unit: $1/(\mathrm{m}^3 \cdot \mathrm{s})$)

Results and Discussion

Figure 1 shows the discharge current as a function of time. Figure 2 plots the distribution of different charge carriers density before and during a current pulse. Figure 3 shows the space charge density distribution at $t = 19$ µs.

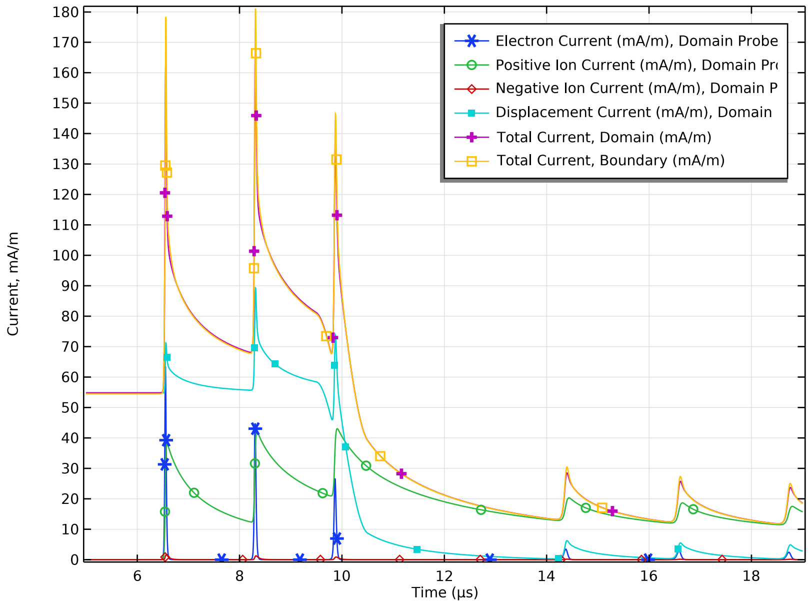


Figure 1: The positive glow corona discharge current and its components due to different charge carriers.

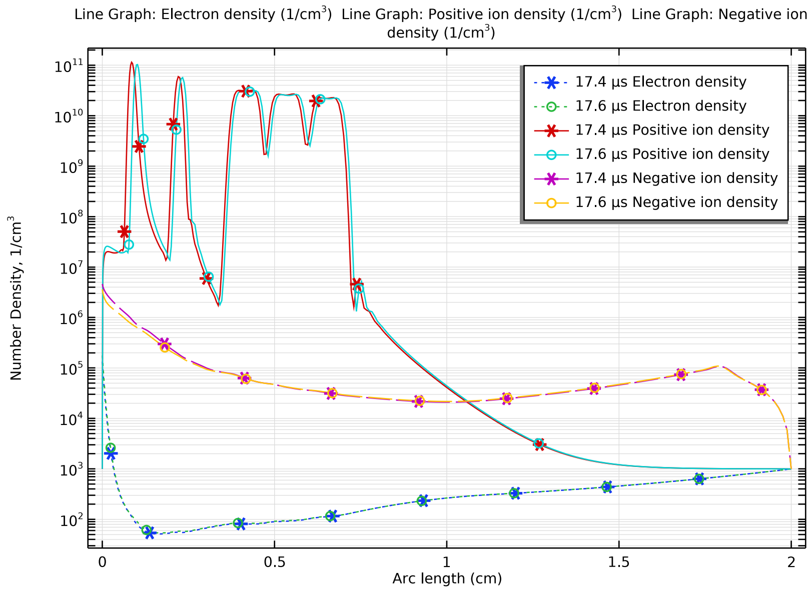


Figure 2: The radial distributions of electron density, positive ion density, and negative ion density at t = 17.4 µs and t = 17.6 µs.

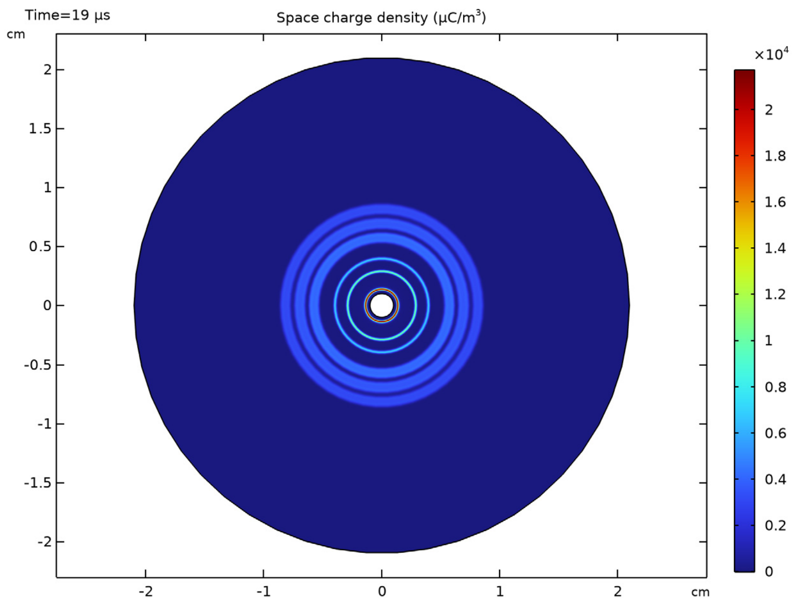


Figure 3: The distribution of space charge density at t = 19 µs.

References

1. R. Morrow, “The theory of positive glow corona,” *J. Phys. D: Appl. Phys.*, vol. 30, no. 22,p. 3099, 1997.

Application Library path: `Electric_Discharge_Module/Corona_Discharges/positive_glow_corona`

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 **1D Axisymmetric**.

2 In the **Select Physics** tree, select **Electric Discharge** > **Electric Discharge (edis)**.

3 Click **Add**.

4 Click **Study**.

5 In the **Select Study** tree, select **Preset Studies for Selected Physics Interfaces** > **Time Dependent with Initialization**.

6 Click **Done**.

GLOBAL DEFINITIONS

Parameters 1

1 In the **Model Builder** window, under **Global Definitions** click **Parameters 1**.

2 In the **Settings** window for **Parameters**, locate the **Parameters** section.

3 In the table, enter the following settings:

Name	Expression	Value	Description
ri	0.1[cm]	0.001 m	Inner Radius
ro	2.1[cm]	0.021 m	Outer Radius
t	5[us]	5E-6 s	Simulation Starting Time
V0	rm1(t/1[us])*1[kV]		Applied Voltage

Ramp 1 (rm1)

1 In the **Home** toolbar, click f(x) **Functions** and choose **Global** > **Ramp**.

2 In the **Settings** window for **Ramp**, locate the **Parameters** section.

3 In the **Slope** text field, type 3.

4 Select the **Cutoff** checkbox. In the associated text field, type 30.

5 Click to expand the **Smoothing** section.

6 Select the **Size of transition zone at cutoff** checkbox. In the associated text field, type 1.

GEOMETRY 1

1 In the **Model Builder** window, expand the **Component 1 (comp1)** > **Geometry 1** node, then click **Geometry 1**.

2 In the **Settings** window for **Geometry**, locate the **Units** section.

3 From the **Length unit** list, choose **cm**.

Interval 1 (i1)

1. Right-click **Geometry 1** and choose **Interval**.
2. In the **Settings** window for **Interval**, locate the **Interval** section.
3. In the table, enter the following settings:

Coordinates (cm)
`ri`
`ro`

ELECTRIC DISCHARGE (EDIS)

Gas 1

In the **Model Builder** window, under **Component 1 (comp1)** > **Electric Discharge (edis)** click **Gas 1**.

Electrode 1

1. In the **Physics** toolbar, click **Attributes** and choose **Electrode**.
2. Select Boundary 2 only.
3. In the **Settings** window for **Electrode**, locate the **Charge Transport** section.
4. From the **Boundary condition for electrons** list, choose **Number density**.
5. From the **Boundary condition for negative ions** list, choose **Number density**.

Gas 1

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

Electrode 2

1. In the **Physics** toolbar, click **Attributes** and choose **Electrode**.
2. Select Boundary 1 only.
3. In the **Settings** window for **Electrode**, locate the **Terminal** section.
4. In the V_0 text field, type `V0`.
5. Locate the **Charge Transport** section. From the **Boundary condition for positive ions** list, choose **Number density**.

Gas 1

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

Photoionization 1

In the **Physics** toolbar, click **Attributes** and choose **Photoionization**.

ADD MATERIAL

1 In the **Materials** toolbar, click **Add Material** to open the **Add Material** window.

2 Go to the **Add Material** window.

3 In the tree, select **Electric Discharge** > **Gases** > **Air** > **Air [Morrow and Lowke, 1997]**.

4 Right-click and choose **Add to Component 1 (comp1)**.

5 In the **Materials** toolbar, click **Add Material** to close the **Add Material** window.

MESH 1

Edge 1

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

Distribution 1

1 In the **Model Builder** window, 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 `300`.

5 In the **Element ratio** text field, type `10`.

6 Click **Build All**.

DEFINITIONS

Domain Probe 1 (dom1)

1 In the **Model Builder** window, expand the **Component 1 (comp1)** > **Definitions** node.

2 Right-click **Definitions** and choose **Probes** > **Domain Probe**.

3 In the **Settings** window for **Domain Probe**, locate the **Probe Type** section.

4 From the **Type** list, choose **Integral**.

5 Locate the **Expression** section. In the **Expression** text field, type `abs(edis.Jc_er*edis.Er/V0)`.

6 In the **Table and plot unit** field, type `mA/m`.

7 In the **Variable name** text field, type `i_e`.

8 Locate the **Expression** section.

9 Select the **Description** checkbox. In the associated text field, type `Electron Current`.

Domain Probe 2 (dom2)

1 Right-click **Domain Probe 1 (i_e)** and choose **Duplicate**.

2 In the **Settings** window for **Domain Probe**, type `i_p` in the **Variable name** text field.

3 Locate the **Expression** section. In the **Expression** text field, type `abs(edis.Jc_pr*edis.Er/V0)`.

4 In the **Description** text field, type `Positive Ion Current`.

Domain Probe 3 (dom3)

1 Right-click **Domain Probe 2 (i_p)** and choose **Duplicate**.

2 In the **Settings** window for **Domain Probe**, type `i_n` in the **Variable name** text field.

3 Locate the **Expression** section. In the **Expression** text field, type `abs(edis.Jc_nr*edis.Er/V0)`.

4 In the **Description** text field, type `Negative Ion Current`.

Domain Probe 4 (dom4)

1 Right-click **Domain Probe 3 (i_n)** and choose **Duplicate**.

2 In the **Settings** window for **Domain Probe**, type `i_d` in the **Variable name** text field.

3 Locate the **Expression** section. In the **Expression** text field, type `edis.Jdr*edis.Er/V0`.

4 In the **Description** text field, type `Displacement Current`.

Global Variable Probe 1 (var1)

1 In the **Definitions** toolbar, click **Probes** and choose **Global Variable Probe**.

2 In the **Settings** window for **Global Variable Probe**, type `i_dom` in the **Variable name** text field.

3 Locate the **Expression** section. In the **Expression** text field, type `i_e+i_p+i_n+i_d`.

4 In the **Table and plot unit** field, type `mA/m`.

5 Select the **Description** checkbox. In the associated text field, type `Total Current, Domain`.

Global Variable Probe 2 (var2)

1 In the **Definitions** toolbar, click **Probes** and choose **Global Variable Probe**.

2 In the **Settings** window for **Global Variable Probe**, type `i_bnd` in the **Variable name** text field.

3 Locate the **Expression** section. In the **Expression** text field, type `edis.I0_1/edis.d`.

4 In the **Table and plot unit** field, type `mA/m`.

5 Select the **Description** checkbox. In the associated text field, type `Total Current, Boundary`.

STUDY 1

Step 2: Time Dependent

1 In the **Model Builder** window, under **Study 1** click **Step 2: Time Dependent**.
2 In the **Settings** window for **Time Dependent**, locate the **Study Settings** section.
3 From the **Time unit** list, choose **µs**.
4 In the **Output times** text field, type `range(5,2,15) range(17,0.2,19)`.

Solution 1 (sol1)

1 In the **Study** toolbar, click **Show Default Solver**.
2 In the **Model Builder** window, click **Study 1**.
3 In the **Settings** window for **Study**, locate the **Study Settings** section.
4 Clear the **Generate default plots** checkbox.
5 In the **Model Builder** window, expand the **Solution 1 (sol1)** node, then click **Time-Dependent Solver 1**.
6 In the **Settings** window for **Time-Dependent Solver**, click to expand the **Time Stepping** section.
7 From the **Maximum step constraint** list, choose **Constant**.
8 In the **Maximum step** text field, type `3[ns]`.
9 In the **Study** toolbar, click **Compute**.

RESULTS

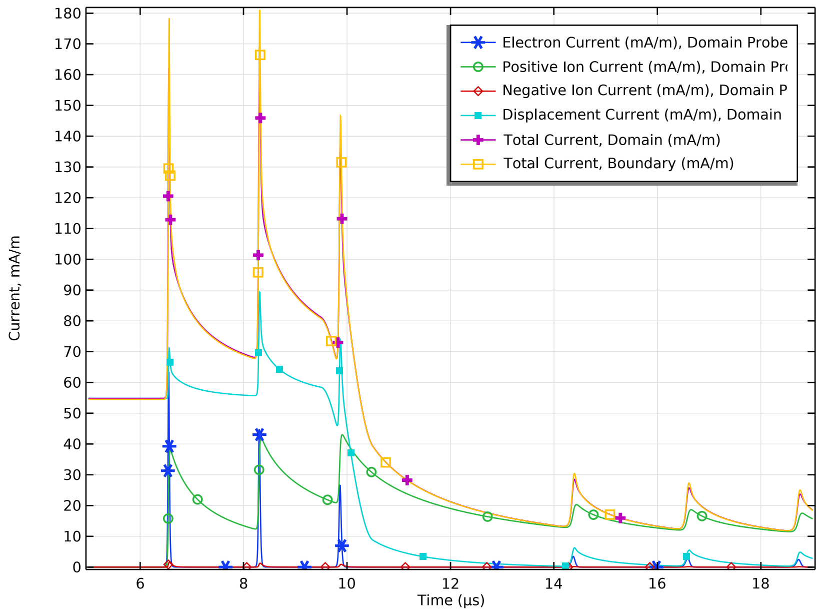
Probe Plot Group 1

1 In the **Model Builder** window, under **Results** click **Probe Plot Group 1**.
2 In the **Settings** window for **1D Plot Group**, locate the **Plot Settings** section.
3 Select the **y-axis label** checkbox. In the associated text field, type `Current, mA/m`.

Probe Table Graph 1

1 In the **Model Builder** window, expand the **Probe Plot Group 1** node, then click **Probe Table Graph 1**.
2 In the **Settings** window for **Table Graph**, locate the **Coloring and Style** section.
3 Find the **Line markers** subsection. From the **Marker** list, choose **Cycle**.

4 In the **Probe Plot Group 1** toolbar, click **Plot**.



1D Plot Group 2

1 In the **Results** toolbar, click **1D Plot Group**.

2 In the **Settings** window for **1D Plot Group**, locate the **Data** section.

3 From the **Dataset** list, choose **None**.

Line Graph 1

1 Right-click **1D Plot Group 2** and choose **Line Graph**.

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

3 From the **Dataset** list, choose **Study 1/Solution 1 (sol1)**.

4 From the **Time selection** list, choose **From list**.

5 In the **Times (µs)** list, choose **17.4** and **17.6**.

6 Select Domain 1 only.

7 Locate the **y-Axis Data** section. In the **Expression** text field, type `edis.n_e`.

8 In the **Unit** field, type `1/cm^3`.

9 Click to expand the **Coloring and Style** section. Find the **Line style** subsection. From the **Line** list, choose **Dotted**.

10 Find the **Line markers** subsection. From the **Marker** list, choose **Cycle (reset)**.

11 From the **Positioning** list, choose **Interpolated**.

12 Click to expand the **Legends** section. Select the **Show legends** checkbox.

13 Find the **Include** subsection. Select the **Description** checkbox.

14 In the **1D Plot Group 2** toolbar, click **Plot**.

Line Graph 2

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 `edis.n_p`.

4 Locate the **Coloring and Style** section. Find the **Line style** subsection. From the **Line** list, choose **Solid**.

Line Graph 3

1 Right-click **Line Graph 2** and choose **Duplicate**.

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

3 In the **Expression** text field, type `edis.n_n`.

4 Locate the **Coloring and Style** section. Find the **Line style** subsection. From the **Line** list, choose **Dashed**.

1D Plot Group 2

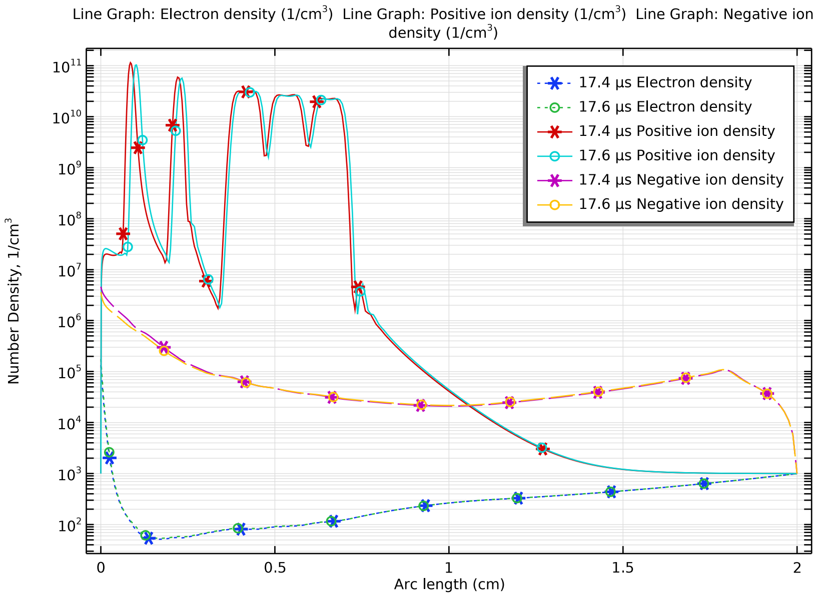
1 In the **Model Builder** window, click **1D Plot Group 2**.

2 In the **Settings** window for **1D Plot Group**, locate the **Plot Settings** section.

3 Select the **y-axis label** checkbox. In the associated text field, type `Number Density, 1/cm<sup>3</sup>`.

4 Click the **y-Axis Log Scale** button in the **Graphics** toolbar.

5 In the **1D Plot Group 2** toolbar, click **Plot**.



Revolution 1D 1

1 In the **Model Builder** window, expand the **Results** > **Datasets** node.

2 Right-click **Results** > **Datasets** and choose **Revolution 1D**.

2D Plot Group 3

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

Surface 1

1 In the **Model Builder** window, right-click **2D Plot Group 3** and choose **Surface**.

2 In the **Settings** window for **Surface**, locate the **Expression** section.

3 From the **Unit** list, choose **µC/m^3**.

4 In the **2D Plot Group 3** toolbar, click **Plot**.