Model created in COMSOL Multiphysics 6.4

Positive Streamer Propagation in a Weak Electric Field

Introduction

Understanding the dynamics of positive streamer propagation in weak electric fields is pivotal in various scientific and technological realms, ranging from atmospheric physics to plasma-based technologies. Positive streamers, characterized by their filamentary structure and rapid advancement, play a crucial role in phenomena such as lightning initiation, corona discharges, and electrical breakdown in gases. In this numerical modeling study, we delve into the intricate mechanisms governing the evolution of positive streamers in low electric fields.

One indispensable process driving positive streamer propagation is photoionization, which serves as a fundamental precursor. Photoionization facilitates the generation of seed electrons, thereby enabling subsequent impact ionization at the streamer head. This interplay between photoionization and impact ionization orchestrates the initiation and sustenance of positive streamers in weak electric fields, shaping their intricate morphological characteristics and propagation dynamics.

This case study investigates a positive streamer between point-plate electrodes. Initially, a cluster of electrons and ions is positioned between two electrodes spaced 1 cm apart, subject to a 13 kV voltage. The simulated electric field and electron density is in good agreement with that published in Ref. 1.

Model Definition

The model is two-dimensional and describes the transient behavior of an initial electron seed in the presence of a weak electric field. The Electric Discharge interface is used to simulate the streamer propagation. 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:

$$\nabla \cdot (\varepsilon_r \varepsilon_0 \mathbf{E}) = \rho$$

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

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 the section on *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

The axial electric field and electron number density for several instants during the streamer propagation are shown in Figure 1 and Figure 2, respectively. Figure 3 shows the photoionization rate at $t = 23$ ns.

The mesh dependency observed in the numerical modeling of positive streamer propagation underscores the intricate balance between mesh resolution and computational accuracy. As noted, the results of the simulations are sensitive to changes in mesh refinement, highlighting the need for careful consideration in mesh selection to adequately capture the nonlinear dynamics inherent in streamer propagation.

A key aspect contributing to mesh dependency is the challenge of resolving the highly nonlinear nature of streamer dynamics. The current mesh employed in the simulations may not possess sufficient resolution to accurately represent the intricate streamer evolution details. Consequently, as the mesh is refined, the results may exhibit variations due to better resolution of the underlying physics.

Interestingly, while mesh refinement introduces instability into the numerical scheme, this instability is instrumental in reproducing the filamentary structure characteristics of streamers. The interplay between mesh-induced instability and the inherent nonlinear dynamics of streamers gives rise to the formation of filamentary structures, crucial for accurately modeling streamer propagation.

Moreover, it is worth noting that separate studies have indicated that, under certain conditions, the model converges to a state where only a diffusive glow corona is formed. This convergence highlights the importance of considering the broader context of streamer dynamics and the limitations of numerical models in capturing all aspects of the phenomenon.

Referring to prior research, it is evident that mesh dependency can arise from various sources. For instance, in Ref. 1, adaptive mesh refinement induces instability, thereby influencing the simulation results. This further emphasizes the need for careful validation and verification of numerical models, taking into account the influence of mesh resolution and other computational parameters.

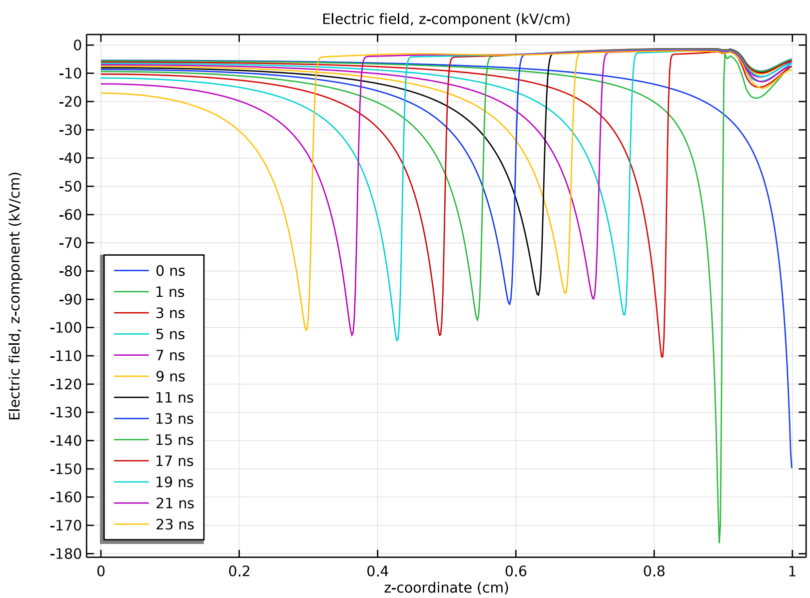


Figure 1: The axial electric field at several time instants during the streamer propagation.

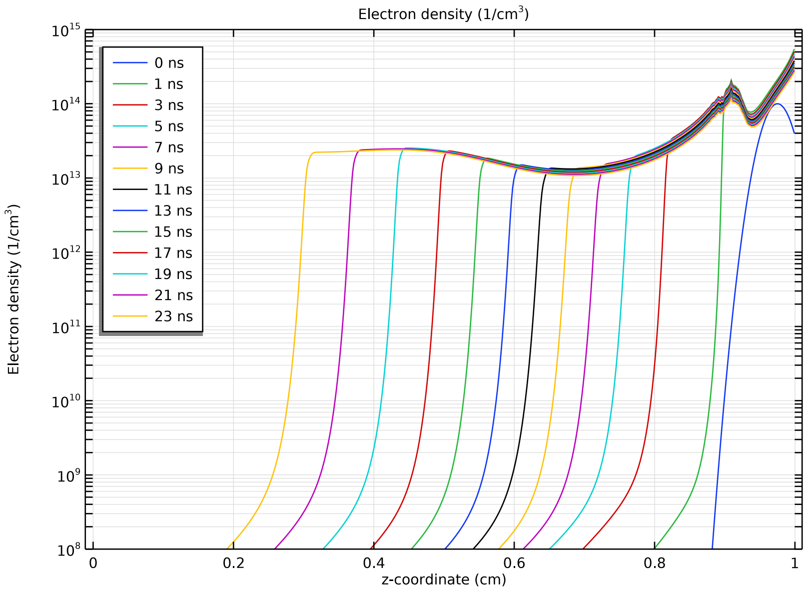


Figure 2: The electron number density at several time instants during the streamer propagation.

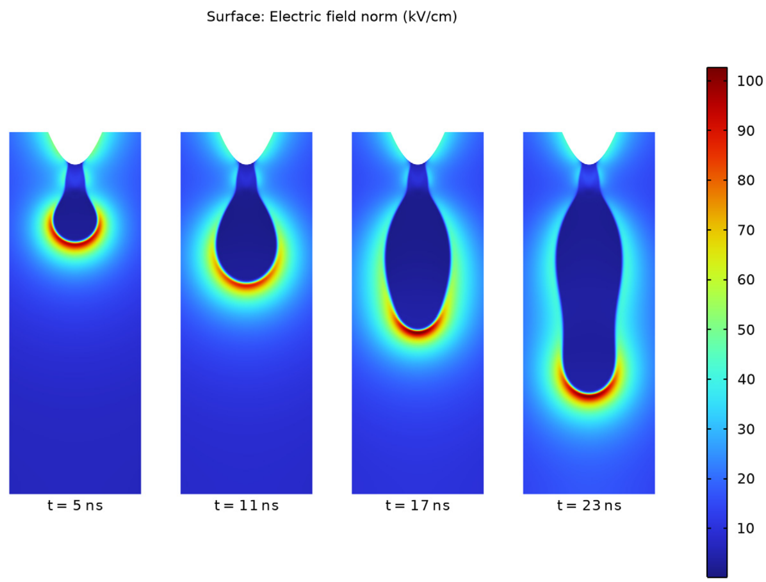


Figure 3: The distribution of electric field at different time instants.

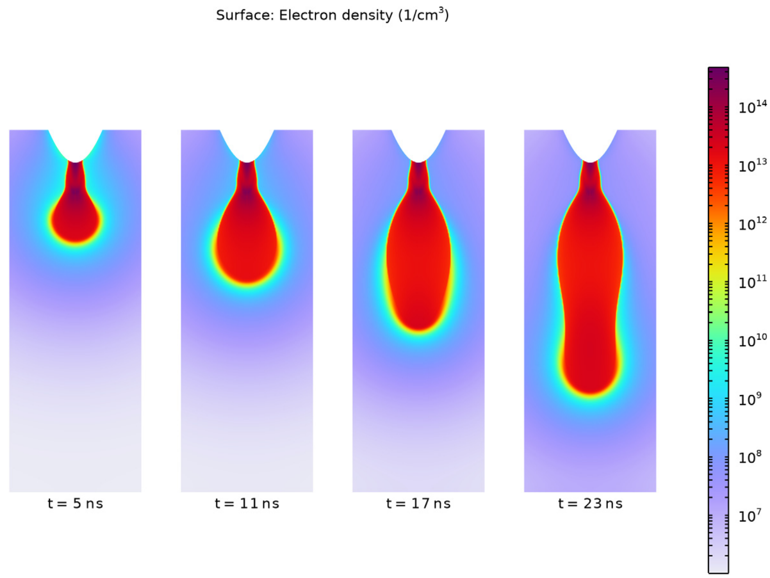


Figure 4: The distribution of electron density at different time instants.

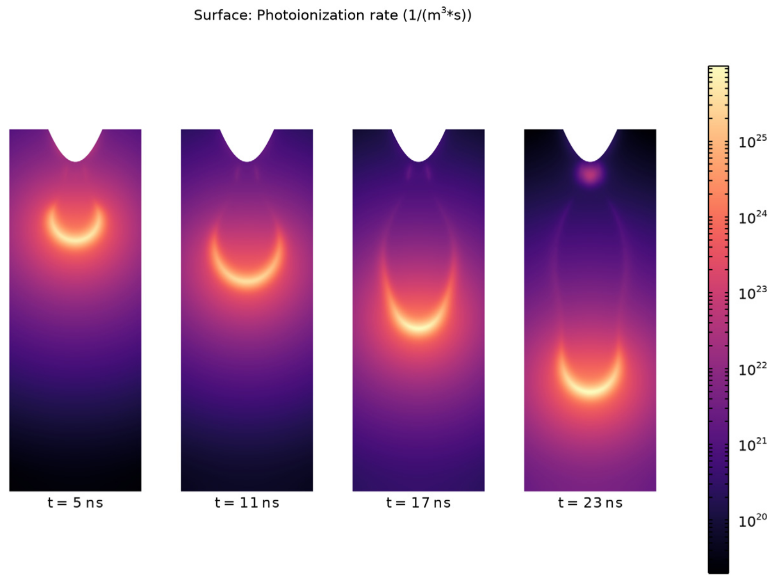


Figure 5: The distribution of photoionization rate at different time instants.

References

1. A.A. Kulikovsky, "Positive streamer in a weak field in air: A moving avalanche-to-streamer transition," *Phys. Rev. E*, vol. 57, no. 6, pp. 7066–7074, 1998.

Application Library path: `Electric_Discharge_Module/Streamer_Discharges/streamer_in_weak_field`

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 **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
V0	13[kV]	13000 V	Applied voltage
De	1800[cm^2/s]	0.18 m²/s	Electron diffusion coefficient

GEOMETRY 1

1 In the **Model Builder** window, under **Component 1 (comp1)** click **Geometry 1**.
2 In the **Settings** window for **Geometry**, locate the **Units** section.
3 From the **Length unit** list, choose **cm**.

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 5.
4 In the **Height** text field, type 6.
5 Click to expand the **Layers** section. In the table, enter the following settings:

Layer name	Thickness (cm)
Layer 1	0.2

6 Clear the **Layers on bottom** checkbox.
7 Select the **Layers to the left** checkbox.

8 Click **Build Selected**.

Parametric Curve 1 (pc1)

1 In the **Geometry** toolbar, click **More Primitives** and choose **Parametric Curve**.

2 In the **Settings** window for **Parametric Curve**, locate the **Parameter** section.

3 In the **Maximum** text field, type `pi*0.45`.

4 Locate the **Expressions** section. In the **r** text field, type `0.18*tan(s)`.

5 In the **z** text field, type `1/cos(s)`.

6 Click **Build Selected**.

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

Line Segment 1 (ls1)

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

2 On the object **pc1**, select Point 2 only.

3 In the **Settings** window for **Line Segment**, locate the **Endpoint** section.

4 Click to select the **Activate Selection** toggle button for **End vertex**.

5 On the object **r1**, select Point 2 only.

Line Segment 2 (ls2)

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

2 On the object **ls1**, select Point 2 only.

3 In the **Settings** window for **Line Segment**, locate the **Endpoint** section.

4 Click to select the **Activate Selection** toggle button for **End vertex**.

5 On the object **pc1**, select Point 1 only.

Convert to Solid 1 (csol1)

1 In the **Geometry** toolbar, click **Conversions** and choose **Convert to Solid**.

2 Select the objects **ls1**, **ls2**, and **pc1** only.

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 **Height** text field, type `0.1`.

4 In the **Width** text field, type `0.2`.

5 Locate the **Position** section. In the **z** text field, type `1-1/1000`.

Difference 1 (dif1)

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

2 Select the objects **r1** and **r2** only.

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

4 Click to select the **Activate Selection** toggle button for **Objects to subtract**.

5 Select the object **csol1** only.

6 Click **Build All Objects**.

ELECTRIC DISCHARGE (EDIS)

Gas 1

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

2 In the **Settings** window for **Gas**, locate the **Model Formulation** section.

3 Clear the **Include background ionization** checkbox.

4 Locate the **Transport Properties** section. Find the **Diffusion** subsection. From the **Diffusion coefficient** list, choose **User defined**.

5 In the D_e text field, type `De`.

6 In the D_p text field, type `0`.

7 In the D_n text field, type `0`.

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 [Kulikovsky, 1998]**.

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

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

MATERIALS

Air [Kulikovsky, 1998] (mat1)

1 In the **Settings** window for **Material**, locate the **Material Contents** section.

2 In the table, enter the following settings:

Property	Variable	Value	Unit	Property group
Positive ion mobility	mu_p_iso ; mu_pii = mu_p_iso, mu_pij = 0	0	m²/(V·s)	Charge transport in gases
Negative ion mobility	mu_n_iso ; mu_nii = mu_n_iso, mu_nij = 0	0	m²/(V·s)	Charge transport in gases

DEFINITIONS

Variables 1

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

2 Right-click **Definitions** and choose **Variables**.

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

4 In the table, enter the following settings:

Name	Expression	Unit	Description
`Ne0`	`(1e6+1e14*exp(-(((z-0.975[cm])/(1[cm]))/0.025)^2-(r/(1[cm])/0.01)^2))[cm^-3]`	1/m³	`Initial electron density`
`Nn0`	`(1e6+1e11*exp(-(((z-0.975[cm])/(1[cm]))/0.025)^2-(r/(1[cm])/0.01)^2))[cm^-3]`	1/m³	`Initial negative ion density`
`Np0`	`Ne0+Nn0`	1/m³	`Initial positive ion density`

ELECTRIC DISCHARGE (EDIS)

Initial Values 1

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

2 In the **Settings** window for **Initial Values**, locate the **Initial Values** section.

3 In the n_e text field, type `Ne0`.

4 In the n_p text field, type `Np0`.

5 In the n_n text field, type `Nn0`.

Gas 1

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

Electrode 1

1. In the **Physics** toolbar, click **Attributes** and choose **Electrode**.
2. Select Boundaries 12–14 only.
3. In the **Settings** window for **Electrode**, locate the **Terminal** section.
4. In the V_0 text field, type V0.

Gas 1

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

Electrode 2

1. In the **Physics** toolbar, click **Attributes** and choose **Electrode**.
2. Select Boundaries 2 and 7 only.

Gas 1

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

Photoionization 1

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

MESH 1

Mapped 1

1. In the **Mesh** toolbar, click **Mapped**.
2. In the **Settings** window for **Mapped**, locate the **Domain Selection** section.
3. From the **Geometric entity level** list, choose **Domain**.
4. Select Domain 1 only.
5. Click the **Zoom Box** button in the **Graphics** toolbar.

Distribution 1

1. Right-click **Mapped 1** and choose **Distribution**.
2. Select Boundaries 2 and 4 only.
3. In the **Settings** window for **Distribution**, locate the **Distribution** section.
4. From the **Distribution type** list, choose **Predefined**.
5. In the **Number of elements** text field, type 80.
6. In the **Element ratio** text field, type 3.

7 Select the **Reverse direction** checkbox.

Distribution 2

1 In the **Model Builder** window, right-click **Mapped 1** and choose **Distribution**.

2 Select Boundaries 1 and 6 only.

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

4 In the **Number of elements** text field, type 600.

Free Triangular 1

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

2 In the **Settings** window for **Free Triangular**, locate the **Domain Selection** section.

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

4 Select Domains 2 and 3 only.

Size 1

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

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

3 Click the **Custom** button.

4 Locate the **Element Size Parameters** section.

5 Select the **Maximum element size** checkbox. In the associated text field, type 1/150.

Free Triangular 2

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

Boundary Layers 1

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

2 Click the **Zoom Out** button in the **Graphics** toolbar.

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

Boundary Layer Properties

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

2 Select Boundaries 12 and 13 only.

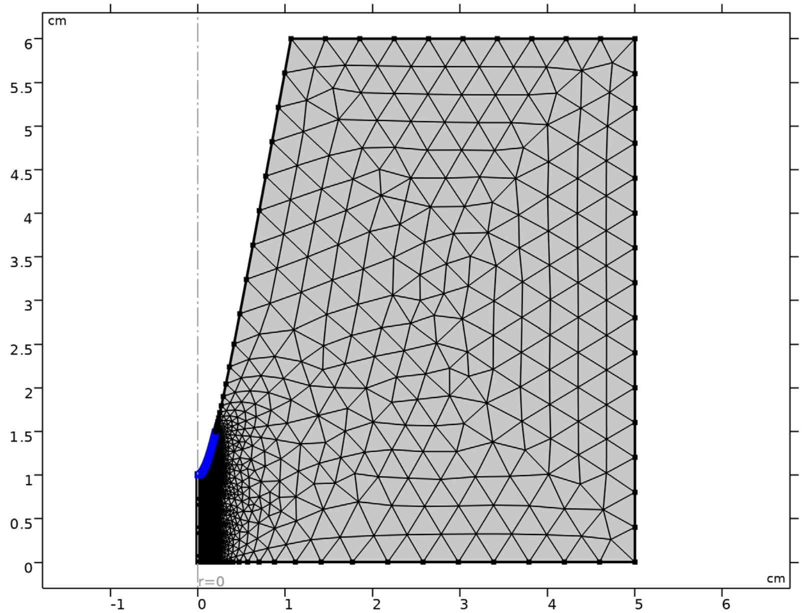
3 In the **Settings** window for **Boundary Layer Properties**, locate the **Layers** section.

4 In the **Number of layers** text field, type 3.

5 In the **Stretching factor** text field, type 1.5.

6 Click **Build All**.

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



STUDY 1

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

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

3 Clear the **Generate default plots** checkbox.

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 **ns**.

4 In the **Output times** text field, type `0 range(1,2,23)`.

Solution 1 (sol1)

1 In the **Study** toolbar, click **Show Default Solver**.

2 In the **Model Builder** window, expand the **Solution 1 (sol1)** node.

3 In the **Model Builder** window, under **Study 1** > **Solver Configurations** > **Solution 1 (sol1)** click **Time-Dependent Solver 1**.

4 In the **Settings** window for **Time-Dependent Solver**, click to expand the **Time Stepping** section.

5 From the **Maximum step constraint** list, choose **Constant**.

6 In the **Maximum step** text field, type `0.025`.

7 In the **Model Builder** window, under **Study 1** > **Solver Configurations** > **Solution 1 (sol1)** > **Time-Dependent Solver 1** click **Segregated 1**.

8 In the **Settings** window for **Segregated**, locate the **General** section.

9 From the **Stabilization and acceleration** list, choose **Anderson acceleration**.

10 Right-click **Study 1** > **Solver Configurations** > **Solution 1 (sol1)** > **Time-Dependent Solver 1** > **Segregated 1** and choose **Segregated Step**.

11 Drag and drop Study 1 > **Solver Configurations** > **Solution 1 (sol1)** > **Time-Dependent Solver 1** > **Segregated 1** > **Segregated Step 4below Segregated Step 1**.

12 In the **Model Builder** window, under **Study 1** > **Solver Configurations** > **Solution 1 (sol1)** > **Time-Dependent Solver 1** > **Segregated 1** click **Segregated Step 1**.

13 In the **Settings** window for **Segregated Step**, locate the **General** section.

14 In the **Variables** list, choose **Natural Logarithm of the Number Density Multiplied by 1[cm^3] (comp1.edis.logn_p)** and **Natural Logarithm of the Number Density Multiplied by 1[cm^3] (comp1.edis.logn_n)**.

15 Under **Variables**, click **Delete**.

16 Click to expand the **Method and Termination** section. In the **Model Builder** window, under **Study 1** > **Solver Configurations** > **Solution 1 (sol1)** > **Time-Dependent Solver 1** > **Segregated 1** click **Segregated Step 4**.

17 In the **Settings** window for **Segregated Step**, locate the **General** section.

18 Under **Variables**, click **Add**.

19 In the **Add** dialog, in the **Variables** list, choose **Natural Logarithm of the Number Density Multiplied by 1[cm^3] (comp1.edis.logn_n)** and **Natural Logarithm of the Number Density Multiplied by 1[cm^3] (comp1.edis.logn_p)**.

20 Click **OK**.

21 In the **Settings** window for **Segregated Step**, locate the **Method and Termination** section.

22 From the **Jacobian update** list, choose **Once per time step**.

23 In the **Study** toolbar, click **Compute**.

RESULTS

Axial Electric Field

1 In the **Results** toolbar, click **1D Plot Group**.
2 In the **Settings** window for **1D Plot Group**, type `Axial Electric Field` in the **Label** text field.

Line Graph 1

1 Right-click **Axial Electric Field** and choose **Line Graph**.
2 Select Boundary 1 only.
3 In the **Settings** window for **Line Graph**, locate the **y-Axis Data** section.
4 In the **Expression** text field, type `edis.Ez`.
5 In the **Unit** field, type `kV/cm`.
6 Locate the **x-Axis Data** section. From the **Parameter** list, choose **Expression**.
7 In the **Expression** text field, type `z`.

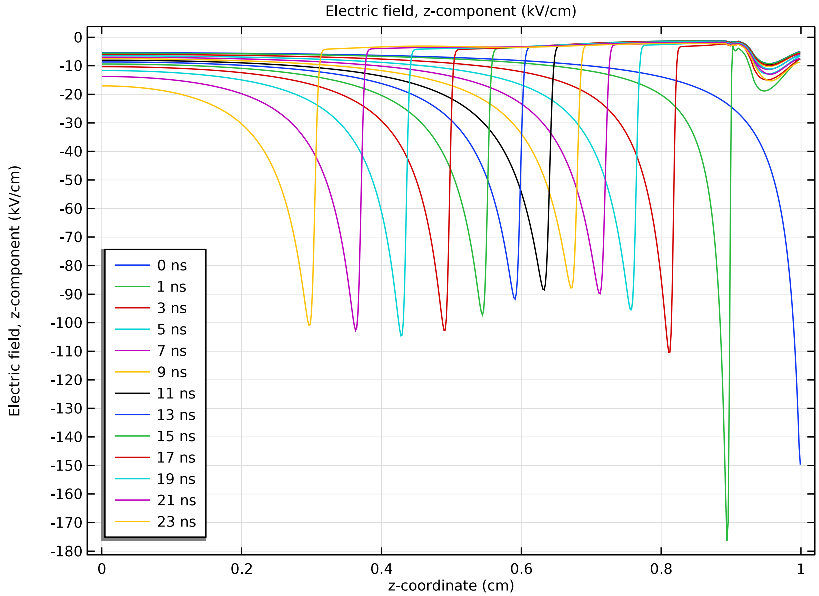
Axial Electric Field

1 In the **Model Builder** window, click **Axial Electric Field**.
2 In the **Settings** window for **1D Plot Group**, locate the **Legend** section.
3 From the **Position** list, choose **Lower left**.

Line Graph 1

1 In the **Model Builder** window, click **Line Graph 1**.
2 In the **Settings** window for **Line Graph**, click to expand the **Legends** section.

3 Select the **Show legends** checkbox.



Electron Density at the Axis

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

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

Line Graph 1

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

2 Select Boundary 1 only.

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

4 In the **Expression** text field, type `edis.n_e`.

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

6 Locate the **x-Axis Data** section. From the **Parameter** list, choose **Expression**.

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

8 Locate the **Legends** section. Select the **Show legends** checkbox.

9 In the **Electron Density at the Axis** toolbar, click **Plot**.

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

Electron Density at the Axis

1 In the **Model Builder** window, click **Electron Density at the Axis**.

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

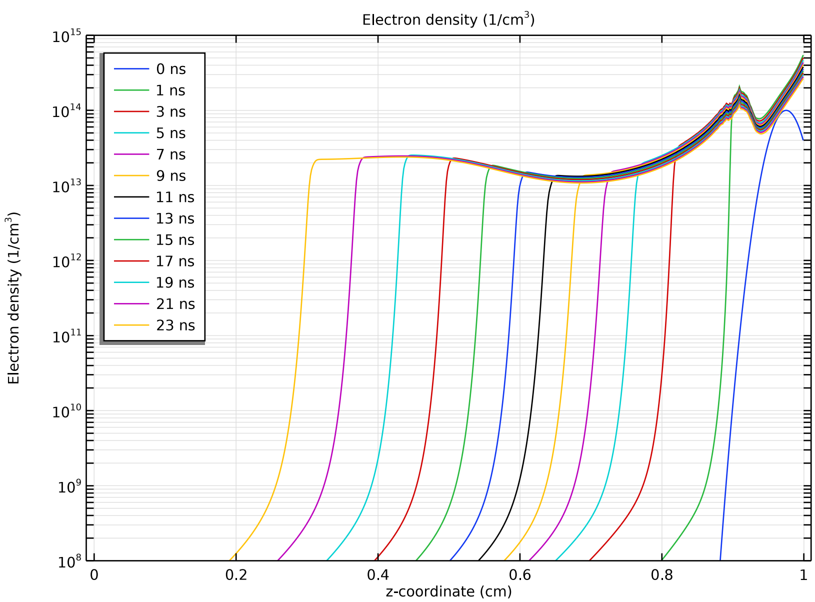
3 Select the **Manual axis limits** checkbox.

4 In the **y minimum** text field, type `1e8`.

5 In the **y maximum** text field, type `1e15`.

6 Locate the **Legend** section. From the **Position** list, choose **Upper left**.

7 In the **Electron Density at the Axis** toolbar, click **Plot**.



Mirror 2D 1

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

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 **Domain**.

4 Select Domains 1 and 2 only.

2D Plot Group 3

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

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

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

4 Locate the **Plot Settings** section. Clear the **Plot dataset edges** checkbox.

Surface 1

1 Right-click **2D Plot Group 3** and choose **Surface**.

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

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

4 In the **Unit** field, type `kV/cm`.

Solution Array 1

1 Right-click **Surface 1** and choose **Solution Array**.

2 In the **Settings** window for **Solution Array**, locate the **Data** section.

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

4 In the **Times (ns)** list, choose **5**, **11**, **17**, and **23**.

Annotation 1

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

2 In the **Settings** window for **Annotation**, locate the **Coloring and Style** section.

3 Clear the **Show point** checkbox.

4 From the **Anchor point** list, choose **Upper middle**.

5 Locate the **Annotation** section. In the **Text** text field, type `t = eval(t,ns,3) ns`.

6 Click to expand the **Plot Array** section. Select the **Manual indexing** checkbox.

Solution Array 1

In the **Model Builder** window, under **Results** > **2D Plot Group 3** > **Surface 1** right-click **Solution Array 1** and choose **Copy**.

Solution Array 1

In the **Model Builder** window, right-click **Annotation 1** and choose **Paste Solution Array**.

Annotation 1

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

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

Electric Field

1 In the **Model Builder** window, under **Results** click **2D Plot Group 3**.

2 In the **Settings** window for **2D Plot Group**, type `Electric Field` in the **Label** text field.

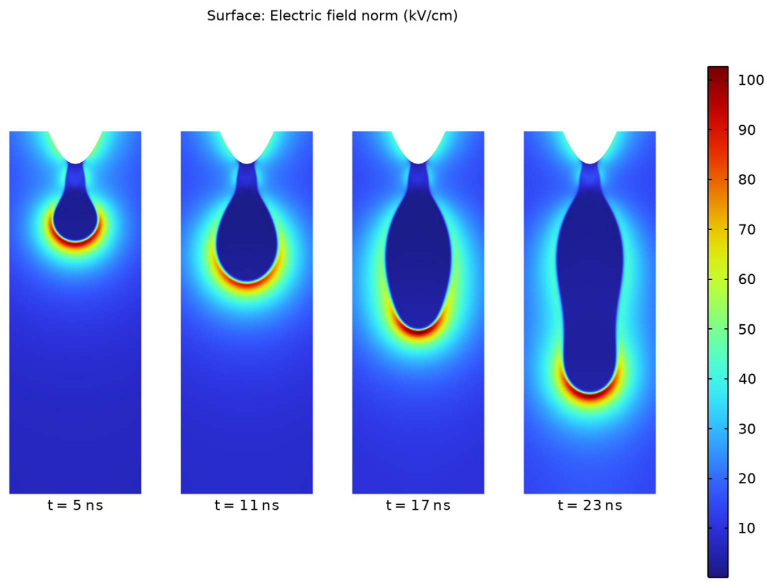
3 Click the **Show Grid** button in the **Graphics** toolbar.

4 Click to expand the **Title** section. From the **Title type** list, choose **Custom**.

5 Find the **Solution** subsection. Clear the **Solution** checkbox.

6 In the **Electric Field** toolbar, click **Plot**.

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



Electric Field 1

Right-click **Electric Field** and choose **Duplicate**.

Surface 1

1 In the **Model Builder** window, expand the **Electric Field 1** node, then click **Surface 1**.

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

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

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

5 Locate the **Coloring and Style** section. From the **Scale** list, choose **Logarithmic**.

6 From the **Color table** list, choose **Prism**.

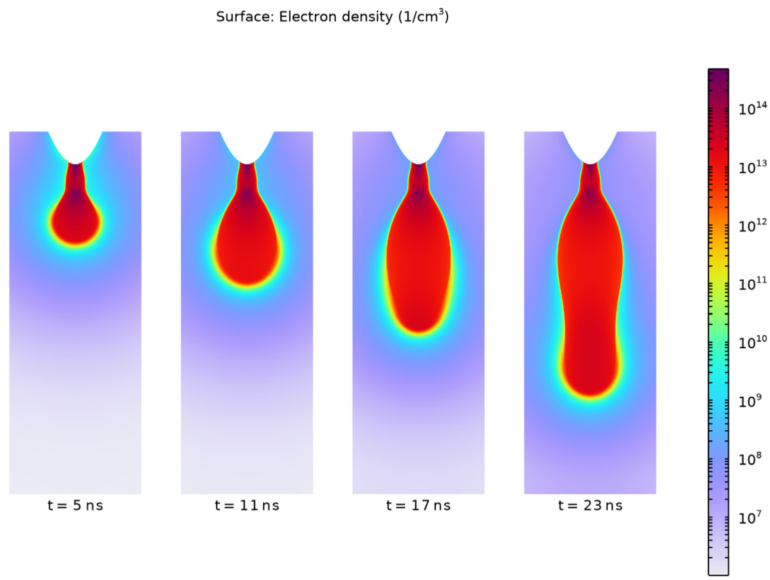
Electron Density

1 In the **Model Builder** window, under **Results** click **Electric Field 1**.

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

3 In the **Electron Density** toolbar, click **Plot**.

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



Electron Density 1

Right-click **Electron Density** and choose **Duplicate**.

Surface 1

1 In the **Model Builder** window, expand the **Electron Density 1** node, then click **Surface 1**.

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

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

4 Locate the **Coloring and Style** section. From the **Color table** list, choose **Magma**.

Photoionization Rate

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

2 In the **Settings** window for **2D Plot Group**, type `Photoionization Rate` in the **Label** text field.

3 In the **Photoionization Rate** toolbar, click **Plot**.

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