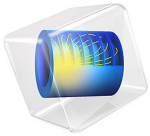


Electrodeless Lamp

Introduction

This model simulates an electrodeless lamp with argon/mercury chemistry. The low excitation threshold for mercury atoms means that even though the mercury is present in small concentrations, its interaction with electrons determines the overall discharge characteristics. here is strong UV emission from the plasma at 185 nm and 253 nm stemming from spontaneous decay of electronically excited mercury atoms. The UV emission can stimulate phosphors coated on the surface of the bulb resulting in visible light. From an electrical point of view, the lamp can be thought of as a transformer, where the coil acts as the primary and the plasma acts as the secondary. If the efficiency of discharge lamps could be increased by 1%, it would result in a saving of 10^9 kWh per year worldwide.

Note: This application requires the Plasma Module and the AC/DC Module.

Model Definition

A schematic of the geometry used to solve the problem is given in Figure 1. A sinusoidal current is applied to the copper coil (green) which creates a magnetic field in the ferrite core (gray). When the plasma ignites, a magnetic circuit is created between the ferrite core and the plasma. The free electrons in the plasma bulk are accelerated by the electric field. This leads to creation of new electrons through ionization which sustains the plasma. In

quasi steady-state, the creation of new electrons is balanced by the loss of electrons to the wall.

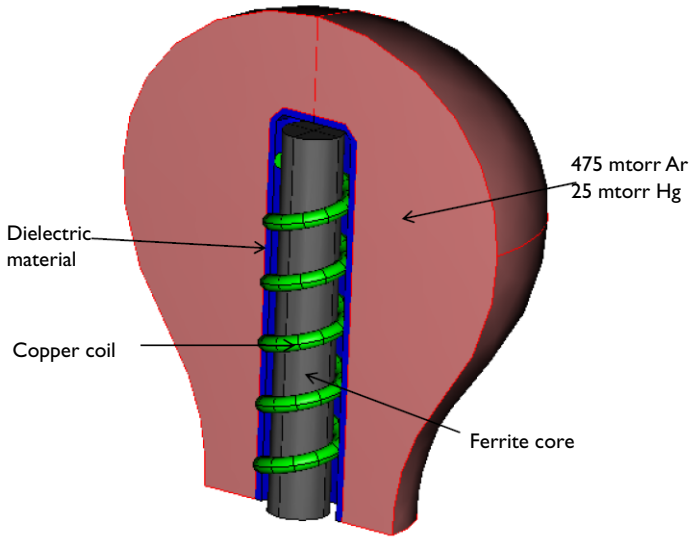


Figure 1: Diagram of electrodeless light source.

The presence of mercury leads to the formation of electronically excited mercury atoms. Certain excited states emit a photon at a given wavelength with a certain emission frequency. By solving for the number density of each of the excited species, you can determine the amount of energy channeled into creating the excited mercury atoms. You can then calculate the amount of energy emitted from the plasma as photons.

In order to simplify the analysis, the following assumptions are made:

- The model is assumed to be axially symmetric.
- The AC induction currents are solved in the frequency domain.
- The electron energy distribution function (EEDF) is assumed to be Maxwellian.
- Thermal quenching of excited atoms is not considered.
- Energy losses in the ferrite core are not considered.
- A trapping factor is used to specify an effective emission photon frequency for the excited mercury atoms. These trapping factors are based on published data.
- The electronically excited argon species are lumped into a single species.

PLASMA CHEMISTRY

The chemical mechanism comes from Ref. 1 and consists of 11 species and 96 reactions. The electron impact cross-section data is obtained from Ref. 2, Ref. 3, Ref. 4, and Ref. 5

TABLE 1: TABLE OF COLLISIONS AND REACTIONS MODELED.

NO	FORMULA	TYPE	$\Delta\varepsilon(\mathrm{eV})$	LEVEL cm^{-1}
1	e+Ar=>e+Ar	Momentum	0	
2	e+Ar=>e+Ar*	Excitation	11.56	
3	e+Ar=>e+e+Ar^+	Ionization	15.80	
4	e+Ar*=>e+Ar	Superelastic	-11.56	
5	e+Ar*=>e+e+Ar^+	Ionization	4.24	
6	e+Hg=>e+Hg	Momentum	0	
7	e+Hg=>e+Hg(63P0)	Excitation	4.66	37645
8	e+Hg=>e+Hg(63P1)	Excitation	4.87	39412
9	e+Hg=>e+Hg(63P2)	Excitation	5.43	44043
10	e+Hg=>e+Hg(61P1)	Excitation	6.70	54069
11	e+Hg=>e+Hg(73S1)	Excitation	7.70	62350
12	e+Hg=>e+Hg(63DJ)	Excitation	8.85	71380
13	e+Hg=>e+e+Hg^+	Ionization	10.44	
14	e+Hg(63P0)=>e+Hg(63P0)	Momentum	0	
15	e+Hg(63P0)=>e+Hg	Superelastic	-4.66	
16	e+Hg(63P0)=>e+Hg(63P1)	Excitation	0.21	
17	e+Hg(63P0)=>e+Hg(63P2)	Excitation	0.77	
18	e+Hg(63P0)=>e+Hg(61P1)	Excitation	2.04	
19	e+Hg(63P0)=>e+Hg(73S1)	Excitation	3.04	
20	e+Hg(63P0)=>e+Hg(63DJ)	Excitation	4.18	
21	e+Hg(63P0)=>e+e+Hg^+	Ionization	5.78	
22	e+Hg(63P1)=>e+Hg(63P1)	Momentum	0	
23	e+Hg(63P1)=>e+Hg	Superelastic	-4.87	
24	e+Hg(63P1)=>e+Hg(63P0)	Superelastic	-0.21	
25	e+Hg(63P1)=>e+Hg(63P2)	Excitation	0.56	
26	e+Hg(63P1)=>e+Hg(61P1)	Excitation	1.83	
27	e+Hg(63P1)=>e+Hg(73S1)	Excitation	2.83	
28	e+Hg(63P1)=>e+Hg(63DJ)	Excitation	3.98	

TABLE 1: TABLE OF COLLISIONS AND REACTIONS MODELED.

NO	FORMULA	TYPE	$\Delta\varepsilon(\mathrm{eV})$	LEVEL cm^{-1}
29	e+Hg(63P1)=>e+e+Hg^+	Ionization	5.57	
30	e+Hg(63P2)=>e+Hg(63P2)	Momentum	0	
31	e+Hg(63P2)=>e+Hg	Superelastic	-5.43	
32	e+Hg(63P2)=>e+Hg(63P0)	Superelastic	-0.77	
33	e+Hg(63P2)=>e+Hg(63P1)	Superelastic	-0.56	
34	e+Hg(63P2)=>e+Hg(61P1)	Excitation	1.27	
35	e+Hg(63P2)=>e+Hg(73S1)	Excitation	2.27	
36	e+Hg(63P2)=>e+Hg(63DJ)	Excitation	3.42	
37	e+Hg(63P2)=>e+e+Hg^+	Ionization	5.01	
38	e+Hg(61P1)=>e+Hg(61P1)	Momentum	0	
39	e+Hg(61P1)=>e+Hg	Superelastic	-6.7	
40	e+Hg(61P1)=>e+Hg(63P0)	Superelastic	-2.04	
41	e+Hg(61P1)=>e+Hg(63P1)	Superelastic	-1.83	
42	e+Hg(61P1)=>e+Hg(63P2)	Superelastic	-1.27	
43	e+Hg(61P1)=>e+e+Hg^+	Ionization	3.74	
44	e+Hg(73S1)=>e+Hg(73S1)	Momentum	0	
45	e+Hg(73S1)=>e+Hg	Superelastic	-7.7	
46	e+Hg(73S1)=>e+Hg(63P0)	Superelastic	-3.04	
47	e+Hg(73S1)=>e+Hg(63P1)	Superelastic	-2.83	
48	e+Hg(73S1)=>e+Hg(63P2)	Superelastic	-2.27	
49	e+Hg(73S1)=>e+e+Hg^+	Ionization	2.74	
50	e+Hg(63DJ)=>e+Hg(63DJ)	Momentum	0	
51	e+Hg(63DJ)=>e+Hg	Superelastic	-8.85	
52	e+Hg(63DJ)=>e+Hg(63P0)	Superelastic	-4.19	
53	e+Hg(63DJ)=>e+Hg(63P1)	Superelastic	-3.98	
54	e+Hg(63DJ)=>e+Hg(63P2)	Superelastic	-3.42	
55	e+Hg(63DJ)=>e+e+Hg^+	Ionization	1.59	
56	Ar*+Ar*=>e+Ar+Ar^+	Penning	0	
57	Ar*+Hg=>e+Ar+Hg^+	Penning	0	
58	Ar*+Hg(63P0)=>e+Ar+Hg^+	Penning	0	
59	Ar*+Hg(63P1)=>e+Ar+Hg^+	Penning	0	

TABLE 1: TABLE OF COLLISIONS AND REACTIONS MODELED.

NO	FORMULA	TYPE	$\Delta\varepsilon(\mathrm{eV})$	LEVEL cm^{-1}
60	Ar*+Hg(63P2)=>e+Ar+Hg^+	Penning	0	
61	Ar*+Hg(61P1)=>e+Ar+Hg^+	Penning	0	
62	Ar*+Hg(73S1)=>e+Ar+Hg^+	Penning	0	
63	Ar*+Hg(63DJ)=>e+Ar+Hg^+	Penning	0	
64	Hg(63P2)+Hg(63P2)=>e+Hg+Hg^+	Penning	0	
65	Hg(63P2)+Hg(63P1)=>e+Hg+Hg^+	Penning	0	
66	Hg(63P2)+Hg(73S1)=>e+Hg+Hg^+	Penning	0	
67	Hg(63P2)+Hg(63DJ)=>e+Hg+Hg^+	Penning	0	
68	Hg(61P1)+Hg(63P0)=>e+Hg+Hg^+	Penning	0	
69	Hg(61P1)+Hg(63P1)=>e+Hg+Hg^+	Penning	0	
70	Hg(61P1)+Hg(63P2)=>e+Hg+Hg^+	Penning	0	
71	Hg(61P1)+Hg(61P1)=>e+Hg+Hg^+	Penning	0	
72	Hg(61P1)+Hg(73S1)=>e+Hg+Hg^+	Penning	0	
73	Hg(61P1)+Hg(63DJ)=>e+Hg+Hg^+	Penning	0	
74	Hg(73S1)+Hg(63P0)=>e+Hg+Hg^+	Penning	0	
75	Hg(73S1)+Hg(63P1)=>e+Hg+Hg^+	Penning	0	
76	Hg(73S1)+Hg(63P2)=>e+Hg+Hg^+	Penning	0	
77	Hg(73S1)+Hg(61P1)=>e+Hg+Hg^+	Penning	0	
78	Hg(73S1)+Hg(73S1)=>e+Hg+Hg^+	Penning	0	
79	Hg(73S1)+Hg(63DJ)=>e+Hg+Hg^+	Penning	0	
80	Hg(63DJ)+Hg(63P0)=>e+Hg+Hg^+	Penning	0	
81	Hg(63DJ)+Hg(63P1)=>e+Hg+Hg^+	Penning	0	
82	Hg(63DJ)+Hg(63P2)=>e+Hg+Hg^+	Penning	0	
83	Hg(63DJ)+Hg(61P1)=>e+Hg+Hg^+	Penning	0	
84	Hg(63DJ)+Hg(73S1)=>e+Hg+Hg^+	Penning	0	
85	Hg(63DJ)+Hg(63DJ)=>e+Hg+Hg^+	Penning	0	
86	Ar^++Hg=>Hg^++Ar	Charge exchange	0	
87	Ar^++Ar=>Ar+Ar^+	Charge exchange	0	
88	Hg^++Hg=>Hg+Hg^+	Charge exchange	0	
89	Hg(63P1)=>Hg	253 nm	0	
90	Hg(61P1)=>Hg	185 nm	0	

TABLE 1: TABLE OF COLLISIONS AND REACTIONS MODELED.

NO	FORMULA	TYPE	$\Delta\varepsilon(\mathrm{eV})$	LEVEL cm^{-1}
91	Hg(73S1)=>Hg(63P0)	405 nm	0	
92	Hg(73S1)=>Hg(63P1)	436 nm	0	
93	Hg(73S1)=>Hg(63P2)	546 nm	0	
94	Hg(63DJ)=>Hg(63P0)	297 nm	0	
95	Hg(63DJ)=>Hg(63P1)	-	0	
96	Hg(63DJ)=>Hg(63P2)	365 nm	0	

The following surface reactions are considered:

TABLE 2: SURFACE REACTIONS.

REACTION	FORMULA
1	Ars=>Ar
2	Ar+=>Ar
3	Hg1=>Hg
4	Hg2=>Hg
5	Hg3=>Hg
6	Hg4=>Hg
7	Hg5=>Hg
8	Hg6=>Hg
9	Hg+=>Hg

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. For detailed information on electron transport, see *Theory for the Drift Diffusion Interface* in the *Plasma Module User's Guide*.

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

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

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. In the case of rate coefficients, the electron source term is given by:

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

where x_j is the mole fraction of the target species for reaction j, k_j is the rate coefficient for reaction j (SI unit: m^3/s), and N_n is the total neutral number density (SI unit: $1/\mathrm{m}^3$). 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 (SI unit: V). The rate coefficients can 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 $\gamma = (2q/m_e)^{1/2}$ (SI unit: $\mathrm{C}^{1/2}/\mathrm{kg}^{1/2}$), m_e is the electron mass (SI unit: kg), ε is energy (SI unit: V), σ_k is the collision cross section (SI unit: m^2), and f is the electron energy distribution function.

For nonelectron 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:

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

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*.

For a nonmagnetized and nonpolarized plasma, the induction currents are computed in the frequency domain using the following equation:

$$(j\omega\sigma - \omega^2\varepsilon_0)\mathbf{A} + \nabla \times (\mu_0^{-1}\nabla \times \mathbf{A}) = \mathbf{J}^e$$

The plasma conductivity needs to be specified as a material property, usually from the cold plasma approximation:

$$\sigma = \frac{n_e q^2}{m_e(\nu_e + j\omega)}$$

where n_e is the electron density, q is the electron charge, m_e is the electron mass, ν_e is the collision frequency and ω is the angular frequency.

ELECTRICAL EXCITATION

The lamp is operated by a fixed power of 80 watts. This means that the total power dissipation in the system is 80 W. Some of the power is lost in the coil and the ferrite but the bulk of the power is channeled into the plasma.

The results are presented below.

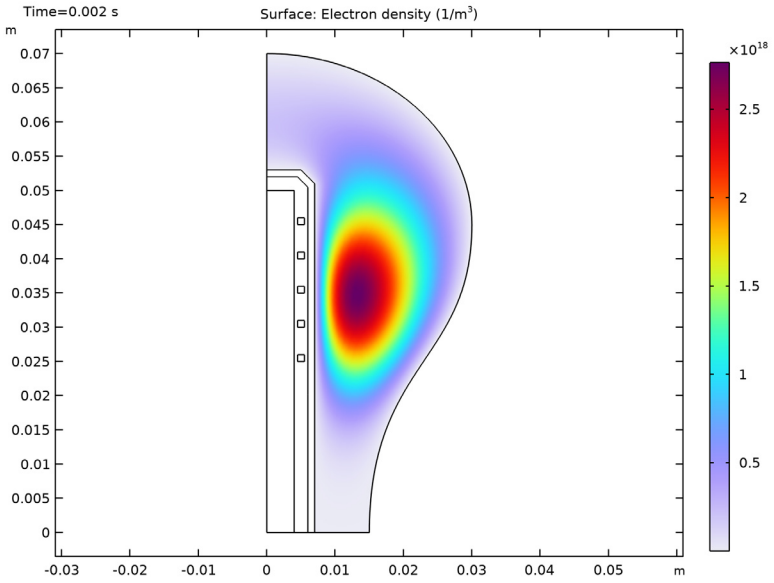


Figure 2: Surface plot of electron density inside the column.

The electron density is plotted in Figure 2. The electron density is high, as one would expect in an inductively coupled plasma. The peak value of the electron density at the driving frequency used in the model results in a peak plasma conductivity of around 180 S/m. The high value for the electron density and low excitation and ionization threshold for mercury results in a very low electron "temperature" which is plotted in Figure 3. The peak electron temperature is only 1.27 eV, which through Boltzmann's relation results in a low plasma potential. The plasma potential is plotted in Figure 4 and only peaks at 8 V.

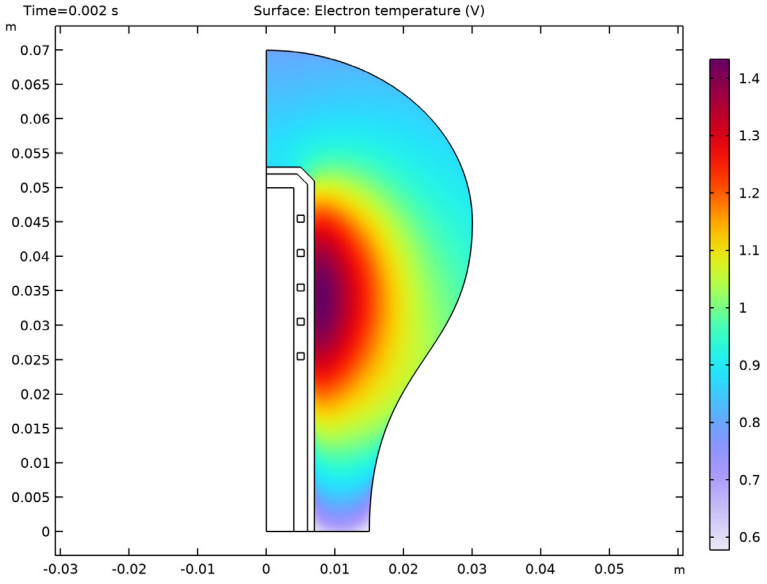


Figure 3: Plot of the electron "temperature".

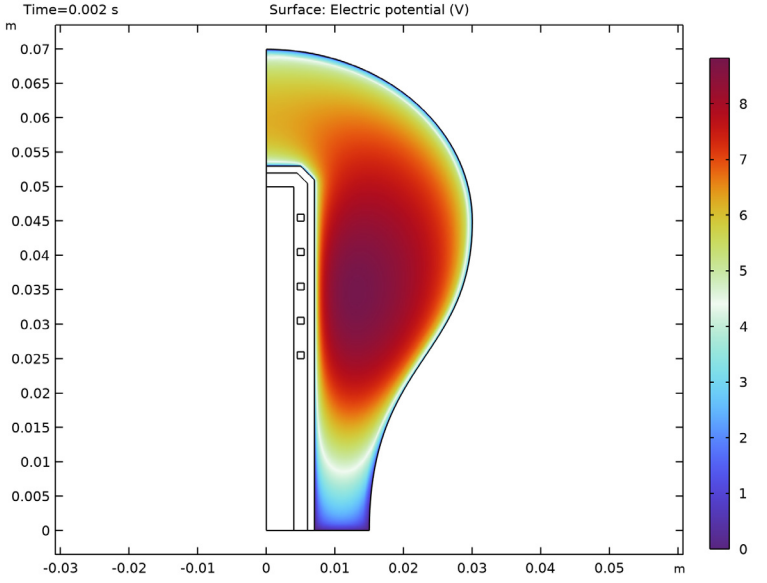


Figure 4: Plot of plasma potential.

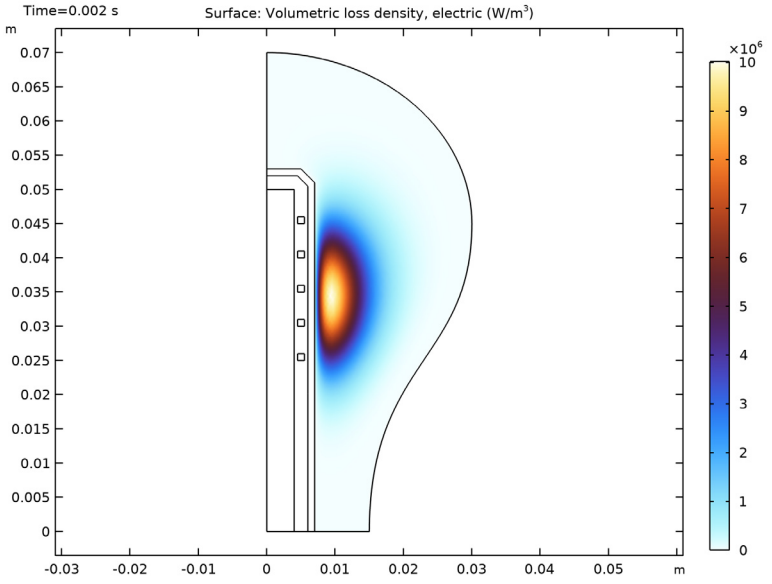


Figure 5: Plot of the resistive losses.

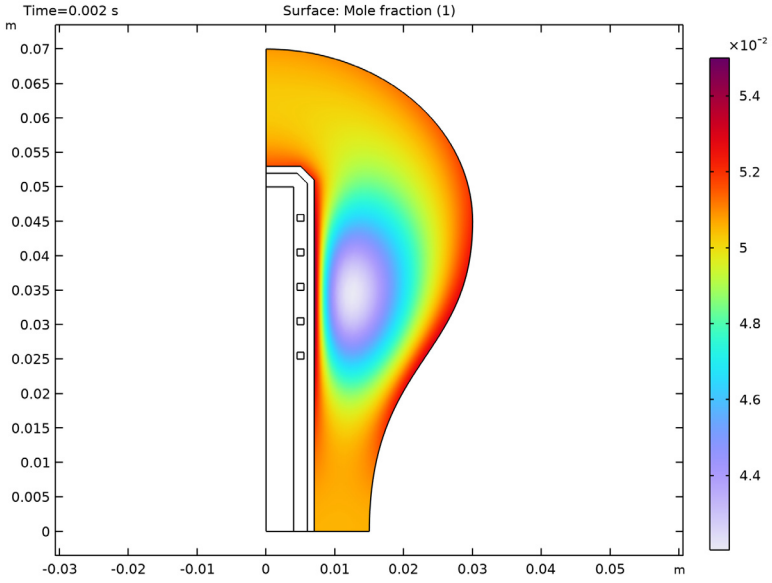


Figure 6: Plot of the mole fraction of ground state mercury.

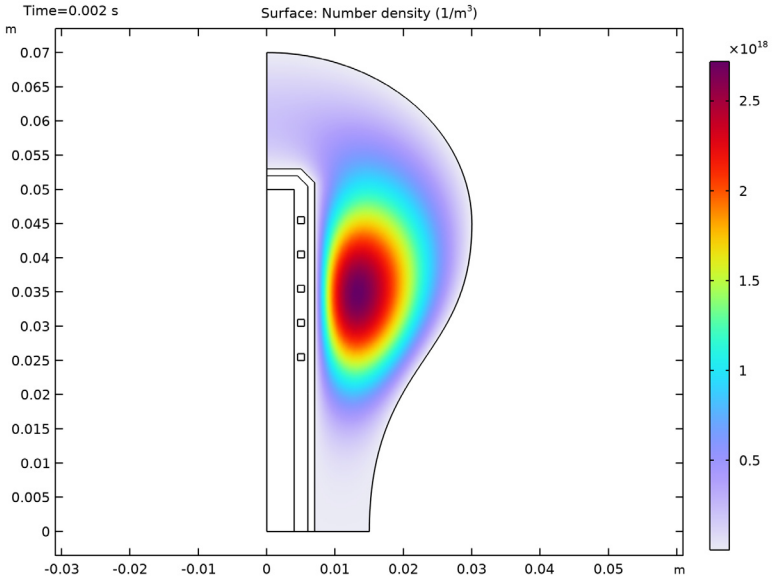


Figure 7: Plot of the number density of mercury ions.

The resistive losses in the plasma are plotted in Figure 5. The plasma skin depth is a few centimeters so there is no real shielding of the azimuthal electric field. The mole fraction of the ground state mercury is plotted in Figure 6. The mole fraction is low in the core of the plasma and higher on the walls. This is because the electrons consume the ground state mercury in the plasma core, converting it to electronically excited states. The electronically excited mercury atoms diffuse to the walls of the lamp where they de-excite back to the ground state. This continuous consumption of ground state mercury in the plasma bulk and release on the walls results in large gradients in mole fraction within the bulb.

There are two ion species present in the plasma, argon, and mercury. Despite the fact that the number density of ground state argon is 25 times higher than mercury, the density of mercury ions is several hundred times greater than the density of argon ions. This is because the ionization energy for mercury is only 10.44 eV compared to 15.7 eV for argon. Direct ionization of mercury is preferable to argon because the tail of the electron energy distribution function drops dramatically at higher electron energies. Additionally, any argon ions which encounter a ground state or electronically excited mercury atom donate their charge because it is energetically favorable.

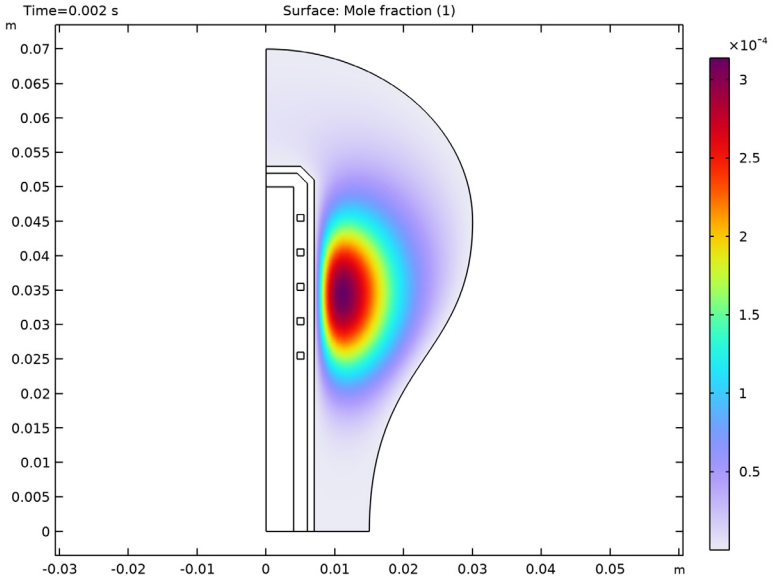


Figure 8: Plot of the mole fraction of Hg(63P1). Spontaneous decay of this species is responsible for the generation of 253 nm radiation.

The mole fraction of Hg(63P1) is plotted in Figure 8. These atoms spontaneously emit photos at a frequency factor of $8 \cdot 10^6$ s^{-1}. On the way to the walls of the lamp, the photons continuously excite mercury atoms and then be released when spontaneous decay occurs. This resonant absorption and reabsorption of the photons means that the frequency factor appears to be much lower than it actually is. Since a self-consistent model of the radiation imprisonment of the photons is computationally impractical, a trapping factor is used to approximate this effect. A trapping factor of 10 is used for the Hg(63P1) atoms which means that the frequency factor is lowered by a factor of 10. In Figure 9 the mole fraction of Hg(61P1) is plotted. A trapping factor of 1000 is used for the spontaneous decay back to ground state mercury.

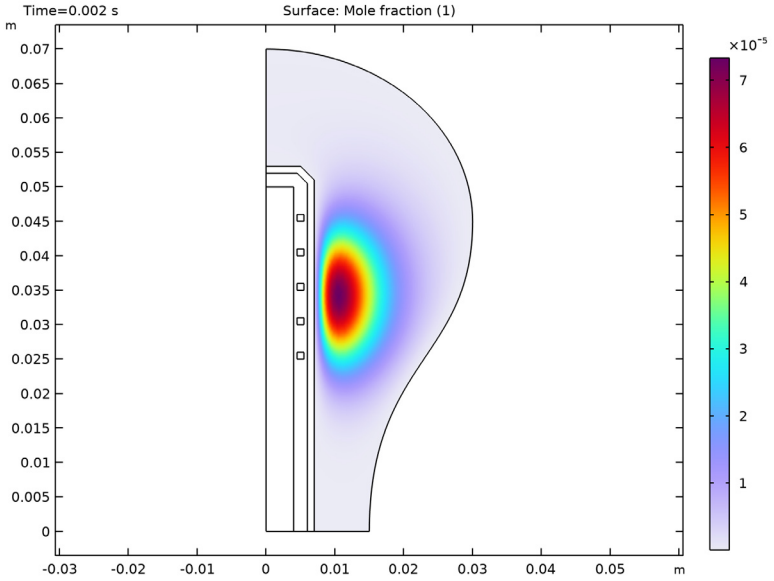


Figure 9: Plot of the mole fraction of Hg(61P1). Spontaneous decay of this species is responsible for the generation of 185 nm radiation.

References

1. K. Rajaraman, *Radiation Transport in Low Pressure Plasmas: Lighting and Semiconductor Etching Plasmas*, PhD thesis, Depart. of Physics, University of Illinois, 2005.

2. Phelps database, www.lxcat.net, retrieve in 2017.

3. S.D.Rockwood, "Elastic and Inelastic Cross Sections for Electron-Hg Scattering from Hg Transport Data", *Phys. Rev. A*, vol. 8, no. 5, pp. 2348–2358, 1973.

4. L.Vriens and A.H.Smeets, "Cross-section and Rate Formulas for Electron-impact Ionization, Excitation, Deexcitation, and Total Depopulation of Excited Atoms", *Phys. Rev. A*, vol. 22, no. 3, pp. 940–951, 1980.

5. C.Kenty, "Production of 2357 Radiation and the Role of Metastables Atoms in an Argon-Mercury Discharges", *Journal of Applied Physics*, vol. 21, pp. 1309–1318, 1950.

Application Library path: `Plasma_Module/Inductively_Coupled_Plasmas/electrodeless_lamp`

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>Inductively Coupled Plasma**.

3 Click **Add**.

4 Click **Study**.

5 In the **Select Study** tree, select **Preset Studies for Selected Multiphysics>Frequency-Transient**.

6 Click **Done**.

GEOMETRY 1

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 In the **r** text field, type `0.015`.

Cubic Bézier 1 (cb1)

1 In the **Geometry** toolbar, click **More Primitives** and choose **Cubic Bézier**.

2 In the **Settings** window for **Cubic Bézier**, locate the **Control Points** section.

3 In row **1**, set **r** to `0.015`.

4 In row **2**, set **r** to `0.015`.

5 In row **3**, set **r** to `0.03`.

6 In row **4**, set **r** to `0.03`.

7 In row **2**, set **z** to `0.025`.

8 In row **3**, set **z** to `0.025`.

9 In row **4**, set **z** to `0.045`.

Quadratic Bézier 1 (qb1)

1 In the **Geometry** toolbar, click **More Primitives** and choose **Quadratic Bézier**.

2 In the **Settings** window for **Quadratic Bézier**, locate the **Control Points** section.

3 In row **1**, set **r** to `0.03`.

4 In row **2**, set **r** to `0.03`.

5 In row **1**, set **z** to `0.045`.

6 In row **2**, set **z** to `0.07`.

7 In row **3**, set **z** to `0.07`.

Line Segment 2 (ls2)

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 `0.07`.

6 Click **Build All Objects**.

Convert to Solid 1 (csol1)

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

2 Click in the **Graphics** window and then press Ctrl+A to select all objects.

3 In the **Settings** window for **Convert to Solid**, click **Build All Objects**.

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 `0.004`.

4 In the **Height** text field, type `0.05`.

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 `0.006`.

4 In the **Height** text field, type `0.052`.

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 `0.007`.

4 In the **Height** text field, type `0.053`.

Chamfer 1 (cha1)

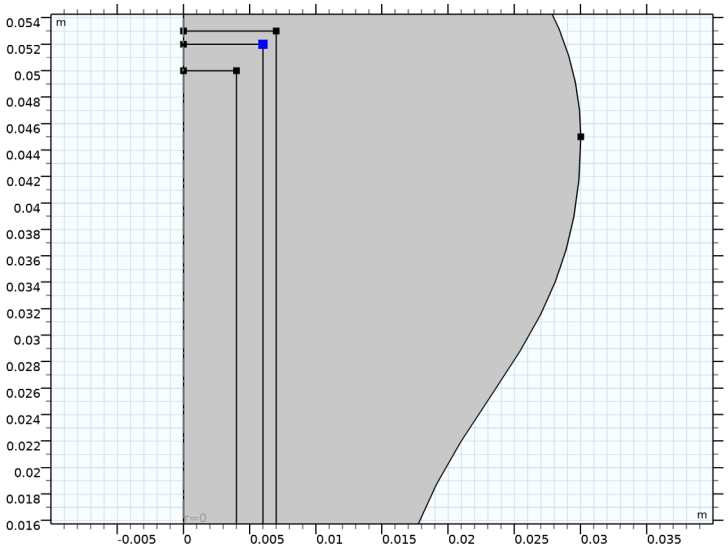
1 In the **Geometry** toolbar, click **Chamfer**.

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

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

4 On the object **r2**, select Point 3 only.

It might be easier to select the correct point by using the **Selection List** window. To open this window, in the **Home** toolbar click **Windows** and choose **Selection List**. (If you are running the cross-platform desktop, you find **Windows** in the main menu.)



5 In the **Settings** window for **Chamfer**, locate the **Distance** section.

6 In the **Distance from vertex** text field, type `1.5e-3`.

7 Click **Build All Objects**.

Chamfer 2 (cha2)

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

2 On the object **r3**, select Point 3 only.

3 In the **Settings** window for **Chamfer**, locate the **Distance** section.

4 In the **Distance from vertex** text field, type `2e-3`.

5 Click **Build All Objects**.

Square 1 (sq1)

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

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

3 In the **Side length** text field, type `0.001`.

4 Locate the **Position** section. In the **r** text field, type `0.0045`.

5 In the **z** text field, type `0.025`.

6 Click **Build All Objects**.

Array 1 (arr1)

1 In the **Geometry** toolbar, click **Transforms** and choose **Array**.

2 Select the object **sq1** only.

3 In the **Settings** window for **Array**, locate the **Size** section.

4 From the **Array type** list, choose **Linear**.

5 In the **Size** text field, type `5`.

6 Locate the **Displacement** section. In the **z** text field, type `5e-3`.

7 Click **Build All Objects**.

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

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
`Tinit`	`350[K]`	K	`Gas temperature`
`pinit`	`101325*(500E-3/760)[Pa]`	Pa	`Initial total pressure`

Name	Expression	Unit	Description
lamp_power	80[W]	W	Lamp power
tf1	10		Trapping factor
tf2	1000		Trapping factor

Coil boundaries

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

2 Select Domains 5–9 only.

3 In the **Settings** window for **Explicit**, locate the **Output Entities** section.

4 From the **Output entities** list, choose **Adjacent boundaries**.

5 In the **Label** text field, type `Coil boundaries`.

Coil domains

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

2 Select Domains 5–9 only.

3 In the **Settings** window for **Explicit**, type `Coil domains` in the **Label** text field.

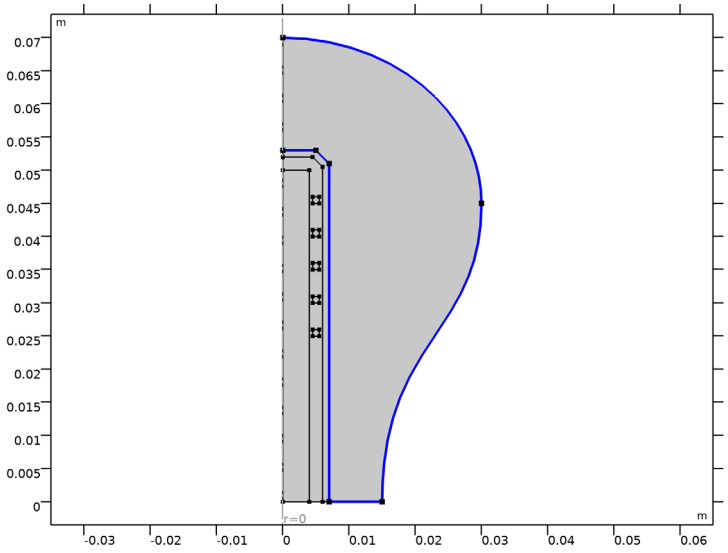
Boundary layers

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

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

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

4 Select Boundaries 8, 27, and 35–38 only.



5 In the **Label** text field, type `Boundary layers`.

Discharge

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

2 Select Domain 4 only.

3 In the **Settings** window for **Explicit**, type `Discharge` in the **Label** text field.

Since the molecular weights of the species are very different, activate the mixture diffusion correction.

PLASMA (PLAS)

1 In the **Model Builder** window, under **Component 1 (comp1)** click **Plasma (plas)**.

2 In the **Settings** window for **Plasma**, locate the **Transport Settings** section.

3 Find the **Include** subsection. Select the **Mixture diffusion correction** check box.

4 Select Domain 4 only.

Cross Section Import 1

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**.

Cross Section Import 2

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 `Hg_xsecs.txt`.

5 Click **Import**.

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=>Ar++Ar+e`.

4 Locate the **Reaction Parameters** section. In the k^f text field, type `N_A_const*1.00E-15[m^3/s]`.

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+Hg=>Hg++Ar+e`.

4 Locate the **Reaction Parameters** section. In the k^f text field, type `N_A_const*9E-16[m^3/s]`.

58: Ars+Hg=>Hg++Ar+e

1 Right-click **57: Ars+Hg=>Hg++Ar+e** and choose **Duplicate**.

2 In the **Settings** window for **Reaction**, locate the **Reaction Formula** section.

3 In the **Formula** text field, type `Ars+Hg1=>Hg++Ar+e`.

59: Ars+Hg1=>Hg++Ar+e

1 Right-click **58: Ars+Hg1=>Hg++Ar+e** and choose **Duplicate**.

2 In the **Settings** window for **Reaction**, locate the **Reaction Formula** section.

3 In the **Formula** text field, type `Ars+Hg2=>Hg++Ar+e`.

60: Ars+Hg2=>Hg++Ar+e

1 Right-click **59: Ars+Hg2=>Hg++Ar+e** and choose **Duplicate**.

2 In the **Settings** window for **Reaction**, locate the **Reaction Formula** section.

3 In the **Formula** text field, type `Ars+Hg3=>Hg++Ar+e`.

61: Ars+Hg3=>Hg++Ar+e

1 Right-click **60: Ars+Hg3=>Hg++Ar+e** and choose **Duplicate**.

2 In the **Settings** window for **Reaction**, locate the **Reaction Formula** section.

3 In the **Formula** text field, type `Ars+Hg4=>Hg++Ar+e`.

62: Ars+Hg4=>Hg++Ar+e

1 Right-click **61: Ars+Hg4=>Hg++Ar+e** and choose **Duplicate**.

2 In the **Settings** window for **Reaction**, locate the **Reaction Formula** section.

3 In the **Formula** text field, type `Ars+Hg5=>Hg++Ar+e`.

63: Ars+Hg5=>Hg++Ar+e

1 Right-click **62: Ars+Hg5=>Hg++Ar+e** and choose **Duplicate**.

2 In the **Settings** window for **Reaction**, locate the **Reaction Formula** section.

3 In the **Formula** text field, type `Ars+Hg6=>Hg++Ar+e`.

64: Ars+Hg6=>Hg++Ar+e

1 Right-click **63: Ars+Hg6=>Hg++Ar+e** and choose **Duplicate**.

2 In the **Settings** window for **Reaction**, locate the **Reaction Formula** section.

3 In the **Formula** text field, type `Hg3+Hg3=>Hg++Hg+e`.

4 Locate the **Reaction Parameters** section. In the k^{f} text field, type `N_A_const*3.50E-16[m^3/s]`.

65: Hg3+Hg3=>Hg++Hg+e

1 Right-click **64: Hg3+Hg3=>Hg++Hg+e** and choose **Duplicate**.

2 In the **Settings** window for **Reaction**, locate the **Reaction Formula** section.

3 In the **Formula** text field, type `Hg3+Hg4=>Hg++Hg+e`.

66: Hg3+Hg4=>Hg++Hg+e

1 Right-click **65: Hg3+Hg4=>Hg++Hg+e** and choose **Duplicate**.

2 In the **Settings** window for **Reaction**, locate the **Reaction Formula** section.

3 In the **Formula** text field, type `Hg3+Hg5=>Hg++Hg+e`.

67: Hg3+Hg5=>Hg++Hg+e

1 Right-click **66: Hg3+Hg5=>Hg++Hg+e** and choose **Duplicate**.

2 In the **Settings** window for **Reaction**, locate the **Reaction Formula** section.

3 In the **Formula** text field, type `Hg3+Hg6=>Hg++Hg+e`.

68: Hg3+Hg6=>Hg++Hg+e

1 Right-click **67: Hg3+Hg6=>Hg++Hg+e** and choose **Duplicate**.

2 In the **Settings** window for **Reaction**, locate the **Reaction Formula** section.

3 In the **Formula** text field, type `Hg4+Hg1=>Hg++Hg+e`.

69: Hg4+Hg1=>Hg++Hg+e

1 Right-click **68: Hg4+Hg1=>Hg++Hg+e** and choose **Duplicate**.

2 In the **Settings** window for **Reaction**, locate the **Reaction Formula** section.

3 In the **Formula** text field, type `Hg4+Hg2=>Hg++Hg+e`.

70: Hg4+Hg2=>Hg++Hg+e

1 Right-click **69: Hg4+Hg2=>Hg++Hg+e** and choose **Duplicate**.

2 In the **Settings** window for **Reaction**, locate the **Reaction Formula** section.

3 In the **Formula** text field, type `Hg4+Hg3=>Hg++Hg+e`.

71: Hg4+Hg3=>Hg++Hg+e

1 Right-click **70: Hg4+Hg3=>Hg++Hg+e** and choose **Duplicate**.

2 In the **Settings** window for **Reaction**, locate the **Reaction Formula** section.

3 In the **Formula** text field, type `Hg4+Hg4=>Hg++Hg+e`.

72: Hg4+Hg4=>Hg++Hg+e

1 Right-click **71: Hg4+Hg4=>Hg++Hg+e** and choose **Duplicate**.

2 In the **Settings** window for **Reaction**, locate the **Reaction Formula** section.

3 In the **Formula** text field, type `Hg4+Hg5=>Hg++Hg+e`.

73: Hg4+Hg5=>Hg++Hg+e

1 Right-click **72: Hg4+Hg5=>Hg++Hg+e** and choose **Duplicate**.

2 In the **Settings** window for **Reaction**, locate the **Reaction Formula** section.

3 In the **Formula** text field, type `Hg4+Hg6=>Hg++Hg+e`.

74: Hg4+Hg6=>Hg++Hg+e

1 Right-click **73: Hg4+Hg6=>Hg++Hg+e** and choose **Duplicate**.

2 In the **Settings** window for **Reaction**, locate the **Reaction Formula** section.

3 In the **Formula** text field, type `Hg5+Hg1=>Hg++Hg+e`.

75: Hg5+Hg1=>Hg++Hg+e

1 Right-click **74: Hg5+Hg1=>Hg++Hg+e** and choose **Duplicate**.

2 In the **Settings** window for **Reaction**, locate the **Reaction Formula** section.

3 In the **Formula** text field, type `Hg5+Hg2=>Hg++Hg+e`.

76: Hg5+Hg2=>Hg++Hg+e

1 Right-click **75: Hg5+Hg2=>Hg++Hg+e** and choose **Duplicate**.

2 In the **Settings** window for **Reaction**, locate the **Reaction Formula** section.

3 In the **Formula** text field, type `Hg5+Hg3=>Hg++Hg+e`.

77: Hg5+Hg3=>Hg++Hg+e

1 Right-click **76: Hg5+Hg3=>Hg++Hg+e** and choose **Duplicate**.

2 In the **Settings** window for **Reaction**, locate the **Reaction Formula** section.

3 In the **Formula** text field, type `Hg5+Hg4=>Hg++Hg+e`.

78: Hg5+Hg4=>Hg++Hg+e

1 Right-click **77: Hg5+Hg4=>Hg++Hg+e** and choose **Duplicate**.

2 In the **Settings** window for **Reaction**, locate the **Reaction Formula** section.

3 In the **Formula** text field, type `Hg5+Hg5=>Hg++Hg+e`.

79: Hg5+Hg5=>Hg++Hg+e

1 Right-click **78: Hg5+Hg5=>Hg++Hg+e** and choose **Duplicate**.

2 In the **Settings** window for **Reaction**, locate the **Reaction Formula** section.

3 In the **Formula** text field, type `Hg5+Hg6=>Hg++Hg+e`.

80: Hg5+Hg6=>Hg++Hg+e

1 Right-click **79: Hg5+Hg6=>Hg++Hg+e** and choose **Duplicate**.

2 In the **Settings** window for **Reaction**, locate the **Reaction Formula** section.

3 In the **Formula** text field, type `Hg6+Hg1=>Hg++Hg+e`.

81: Hg6+Hg1=>Hg++Hg+e

1 Right-click **80: Hg6+Hg1=>Hg++Hg+e** and choose **Duplicate**.

2 In the **Settings** window for **Reaction**, locate the **Reaction Formula** section.

3 In the **Formula** text field, type `Hg6+Hg2=>Hg++Hg+e`.

82: Hg6+Hg2=>Hg++Hg+e

1 Right-click **81: Hg6+Hg2=>Hg++Hg+e** and choose **Duplicate**.

2 In the **Settings** window for **Reaction**, locate the **Reaction Formula** section.

3 In the **Formula** text field, type `Hg6+Hg3=>Hg++Hg+e`.

83: Hg6+Hg3=>Hg++Hg+e

1. Right-click **82: Hg6+Hg3=>Hg++Hg+e** and choose **Duplicate**.
2. In the **Settings** window for **Reaction**, locate the **Reaction Formula** section.
3. In the **Formula** text field, type `Hg6+Hg4=>Hg++Hg+e`.

84: Hg6+Hg4=>Hg++Hg+e

1. Right-click **83: Hg6+Hg4=>Hg++Hg+e** and choose **Duplicate**.
2. In the **Settings** window for **Reaction**, locate the **Reaction Formula** section.
3. In the **Formula** text field, type `Hg6+Hg5=>Hg++Hg+e`.

85: Hg6+Hg5=>Hg++Hg+e

1. Right-click **84: Hg6+Hg5=>Hg++Hg+e** and choose **Duplicate**.
2. In the **Settings** window for **Reaction**, locate the **Reaction Formula** section.
3. In the **Formula** text field, type `Hg6+Hg6=>Hg++Hg+e`.

86: Hg6+Hg6=>Hg++Hg+e

1. Right-click **85: Hg6+Hg6=>Hg++Hg+e** and choose **Duplicate**.
2. In the **Settings** window for **Reaction**, locate the **Reaction Formula** section.
3. In the **Formula** text field, type `Ar++Hg=>Hg++Ar`.
4. Locate the **Reaction Parameters** section. In the k^{f} text field, type `N_A_const*1.50E-17[m^3/s]`.

87: Ar++Hg=>Hg++Ar

1. Right-click **86: Ar++Hg=>Hg++Ar** and choose **Duplicate**.
2. In the **Settings** window for **Reaction**, locate the **Reaction Formula** section.
3. In the **Formula** text field, type `Ar++Ar=>Ar++Ar`.
4. Locate the **Reaction Parameters** section. In the k^{f} text field, type `N_A_const*4.60E-16[m^3/s]`.

88: Ar++Ar=>Ar++Ar

1. Right-click **87: Ar++Ar=>Ar++Ar** and choose **Duplicate**.
2. In the **Settings** window for **Reaction**, locate the **Reaction Formula** section.
3. In the **Formula** text field, type `Hg++Hg=>Hg+Hg+`.
4. Locate the **Reaction Parameters** section. In the k^{f} text field, type `N_A_const*1.00E-15[m^3/s]`.

89: Hg++Hg=>Hg+Hg+

1. Right-click **88: Hg++Hg=>Hg+Hg+** and choose **Duplicate**.

2 In the **Settings** window for **Reaction**, locate the **Reaction Formula** section.

3 In the **Formula** text field, type `Hg2=>Hg`.

4 Locate the **Reaction Parameters** section. In the k^{f} text field, type `8.00E6/tf1`.

90: Hg2=>Hg

1 Right-click **89: Hg2=>Hg** and choose **Duplicate**.

2 In the **Settings** window for **Reaction**, locate the **Reaction Formula** section.

3 In the **Formula** text field, type `Hg4=>Hg`.

4 Locate the **Reaction Parameters** section. In the k^{f} text field, type `7.50E8/tf2`.

91: Hg4=>Hg

1 Right-click **90: Hg4=>Hg** and choose **Duplicate**.

2 In the **Settings** window for **Reaction**, locate the **Reaction Formula** section.

3 In the **Formula** text field, type `Hg5=>Hg1`.

4 Locate the **Reaction Parameters** section. In the k^{f} text field, type `2.2E7`.

92: Hg5=>Hg1

1 Right-click **91: Hg5=>Hg1** and choose **Duplicate**.

2 In the **Settings** window for **Reaction**, locate the **Reaction Formula** section.

3 In the **Formula** text field, type `Hg5=>Hg2`.

4 Locate the **Reaction Parameters** section. In the k^{f} text field, type `6.6E7`.

93: Hg5=>Hg2

1 Right-click **92: Hg5=>Hg2** and choose **Duplicate**.

2 In the **Settings** window for **Reaction**, locate the **Reaction Formula** section.

3 In the **Formula** text field, type `Hg5=>Hg3`.

4 Locate the **Reaction Parameters** section. In the k^{f} text field, type `2E7`.

94: Hg5=>Hg3

1 Right-click **93: Hg5=>Hg3** and choose **Duplicate**.

2 In the **Settings** window for **Reaction**, locate the **Reaction Formula** section.

3 In the **Formula** text field, type `Hg6=>Hg1`.

95: Hg6=>Hg1

1 Right-click **94: Hg6=>Hg1** and choose **Duplicate**.

2 In the **Settings** window for **Reaction**, locate the **Reaction Formula** section.

3 In the **Formula** text field, type `Hg6=>Hg2`.

4 Locate the **Reaction Parameters** section. In the k^f text field, type `6E7`.

96: Hg6=>Hg2

1 Right-click **95: Hg6=>Hg2** and choose **Duplicate**.

2 In the **Settings** window for **Reaction**, locate the **Reaction Formula** section.

3 In the **Formula** text field, type `Hg6=>Hg3`.

4 Locate the **Reaction Parameters** section. In the k^f text field, type `5E7`.

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 `Ars=>Ar`.

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

2: Ars=>Ar

1 Right-click **1: Ars=>Ar** and choose **Duplicate**.

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

3 In the **Formula** text field, type `Ar+=>Ar`.

3: Ar+=>Ar

1 Right-click **2: Ar+=>Ar** and choose **Duplicate**.

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

3 In the **Formula** text field, type `Hg1=>Hg`.

4: Hg1=>Hg

1 Right-click **3: Hg1=>Hg** and choose **Duplicate**.

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

3 In the **Formula** text field, type `Hg2=>Hg`.

5: Hg2=>Hg

1 Right-click **4: Hg2=>Hg** and choose **Duplicate**.

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

3 In the **Formula** text field, type `Hg3=>Hg`.

6: Hg3=>Hg

1 Right-click **5: Hg3=>Hg** and choose **Duplicate**.

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

3 In the **Formula** text field, type `Hg4=>Hg`.

7: Hg4=>Hg

1 Right-click **6: Hg4=>Hg** and choose **Duplicate**.

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

3 In the **Formula** text field, type `Hg5=>Hg`.

8: Hg5=>Hg

1 Right-click **7: Hg5=>Hg** and choose **Duplicate**.

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

3 In the **Formula** text field, type `Hg6=>Hg`.

9: Hg6=>Hg

1 Right-click **8: Hg6=>Hg** and choose **Duplicate**.

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

3 In the **Formula** text field, type `Hg+=>Hg`.

Species: Hg

1 In the **Model Builder** window, click **Species: Hg**.

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

3 In the M_w text field, type `0.2006`.

4 In the σ text field, type `2.969[angstrom]`.

5 In the ε/k_b text field, type `750`.

6 In the x_0 text field, type `0.05`.

Species: Hg1

1 In the **Model Builder** window, click **Species: Hg1**.

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

3 In the M_w text field, type `0.2006`.

4 In the σ text field, type `2.969[angstrom]`.

5 In the ε/k_b text field, type `750`.

6 In the x_0 text field, type `2E-6`.

Species: Hg2

1 In the **Model Builder** window, click **Species: Hg2**.

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

3 In the M_w text field, type `0.2006`.

4 In the σ text field, type `2.969[angstrom]`.

5 In the ε/k_b text field, type `750`.

6 In the x_0 text field, type `1E-6`.

Species: Hg3

1 In the **Model Builder** window, click **Species: Hg3**.

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

3 In the M_w text field, type `0.2006`.

4 In the σ text field, type `2.969[angstrom]`.

5 In the ε/k_b text field, type `750`.

6 In the x_0 text field, type `5E-6`.

Species: Hg4

1 In the **Model Builder** window, click **Species: Hg4**.

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

3 In the M_w text field, type `0.2006`.

4 In the σ text field, type `2.969[angstrom]`.

5 In the ε/k_b text field, type `750`.

6 In the x_0 text field, type `1E-6`.

Species: Hg5

1 In the **Model Builder** window, click **Species: Hg5**.

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

3 In the M_w text field, type `0.2006`.

4 In the σ text field, type `2.969[angstrom]`.

5 In the ε/k_b text field, type `750`.

6 In the x_0 text field, type `5E-6`.

Species: Hg6

1 In the **Model Builder** window, click **Species: Hg6**.

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

3 In the M_w text field, type `0.2006`.

4 In the σ text field, type `2.969[angstrom]`.

5 In the ε/k_b text field, type `750`.

6 In the x_0 text field, type `1E-6`.

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.

Species: Ar+

1 In the **Model Builder** window, click **Species: Ar+**.

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

3 In the n_0 text field, type `1E16`.

Species: Hg+

1 In the **Model Builder** window, click **Species: Hg+**.

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

3 In the M_w text field, type `0.2006`.

4 In the σ text field, type `2.969[angstrom]`.

5 In the ε/k_b text field, type `750`.

6 Locate the **Species Formula** section. Select the **Initial value from electroneutrality constraint** 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 **Electron Density and Energy** section.

3 From the **Electron transport properties** list, choose **From electron impact reactions**.

4 Locate the **Model Inputs** section. In the T text field, type `Tinit`.

5 In the p_A text field, type `pinit`.

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 **Boundary layers**.

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 **Boundary layers**.

Initial Values 1

1 In the **Model Builder** window, click **Initial Values 1**.

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

3 In the $n_{e,0}$ text field, type `1E17`.

4 In the ε_0 text field, type `2`.

MAGNETIC FIELDS (MF)

In the **Model Builder** window, under **Component 1 (comp1)** click **Magnetic Fields (mf)**.

Coil 1

1 In the **Physics** toolbar, click **Domains** and choose **Coil**.

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

3 From the **Selection** list, choose **Coil domains**.

4 Locate the **Coil** section. Select the **Coil group** check box.

5 From the **Coil excitation** list, choose **Power**.

6 In the P_{coil} text field, type `lamp_power`.

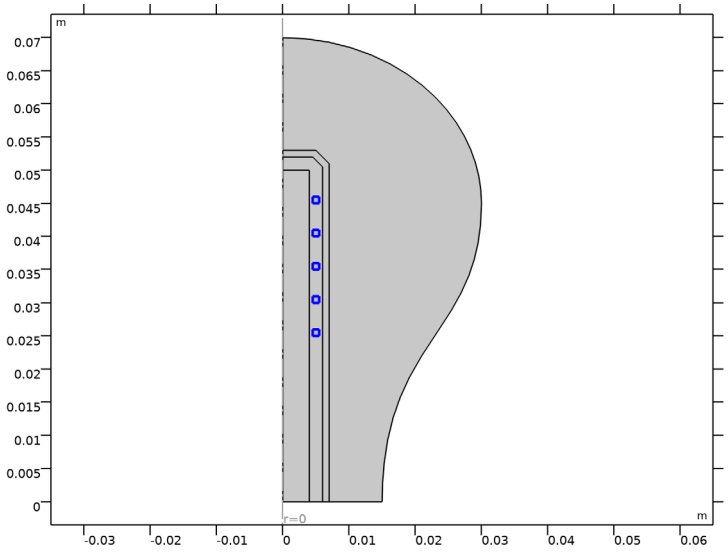
7 Click the **Zoom Extents** button in the **Graphics** toolbar.

MATERIALS

Coils

1 In the **Model Builder** window, under **Component 1 (comp1)** right-click **Materials** and choose **Blank Material**.

2 Select Domains 5–9 only.



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

4 In the table, enter the following settings:

Property	Variable	Value	Unit	Property group
Electrical conductivity	sigma_iso ; sigmaii = sigma_iso, sigmaij = 0	6e7	S/m	Basic
Relative permeability	mur_iso ; murii = mur_iso, murij = 0	1	1	Basic
Relative permittivity	epsilonr_iso ; epsilonrii = epsilonr_iso, epsilonrij = 0	1	1	Basic

5 In the **Label** text field, type `Coils`.

Ferrite

1 Right-click **Materials** and choose **Blank Material**.

2 Select Domain 1 only.

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

4 In the table, enter the following settings:

Property	Variable	Value	Unit	Property group
Relative permeability	mur_iso ; murii = mur_iso, murij = 0	1e3	I	Basic
Electrical conductivity	sigma_iso ; sigmaii = sigma_iso, sigmaij = 0	0	S/m	Basic
Relative permittivity	epsilonr_iso ; epsilonrii = epsilonr_iso, epsilonrij = 0	1	I	Basic

5 In the **Label** text field, type `Ferrite`.

Air

1 Right-click **Materials** and choose **Blank Material**.

2 Select Domain 2 only.

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

4 In the table, enter the following settings:

Property	Variable	Value	Unit	Property group
Relative permeability	mur_iso ; murii = mur_iso, murij = 0	1	I	Basic
Electrical conductivity	sigma_iso ; sigmaii = sigma_iso, sigmaij = 0	0	S/m	Basic
Relative permittivity	epsilonr_iso ; epsilonrii = epsilonr_iso, epsilonrij = 0	1	I	Basic

5 In the **Label** text field, type `Air`.

Dielectric

1 Right-click **Materials** and choose **Blank Material**.

2 Select Domain 3 only.

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

4 In the table, enter the following settings:

Property	Variable	Value	Unit	Property group
Relative permeability	mur_iso ; murii = mur_iso, murij = 0	1	1	Basic
Electrical conductivity	sigma_iso ; sigmaii = sigma_iso, sigmaij = 0	0	S/m	Basic
Relative permittivity	epsilonr_iso ; epsilonrii = epsilonr_iso, epsilonrij = 0	4.2	1	Basic

5 In the **Label** text field, type `Dielectric`.

MESH 1

1 In the **Model Builder** window, under **Component 1 (comp1)** click **Mesh 1**.

2 In the **Settings** window for **Mesh**, locate the **Physics-Controlled Mesh** section.

3 From the **Element size** list, choose **Extra fine**.

Edge 1

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

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

3 From the **Selection** list, choose **Coil boundaries**.

Distribution 1

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

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

3 From the **Selection** list, choose **Coil boundaries**.

4 Locate the **Distribution** section. From the **Distribution type** list, choose **Predefined**.

5 In the **Number of elements** text field, type 30.

6 In the **Element ratio** text field, type `6`.

7 From the **Growth rate** list, choose **Exponential**.

8 Select the **Symmetric distribution** check box.

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 From the **Selection** list, choose **Coil domains**.

Edge 2

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

2 Select Boundaries 8, 27, and 35 only.

Size 1

1 Right-click **Edge 2** and choose **Size**.

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

3 Click the **Custom** button.

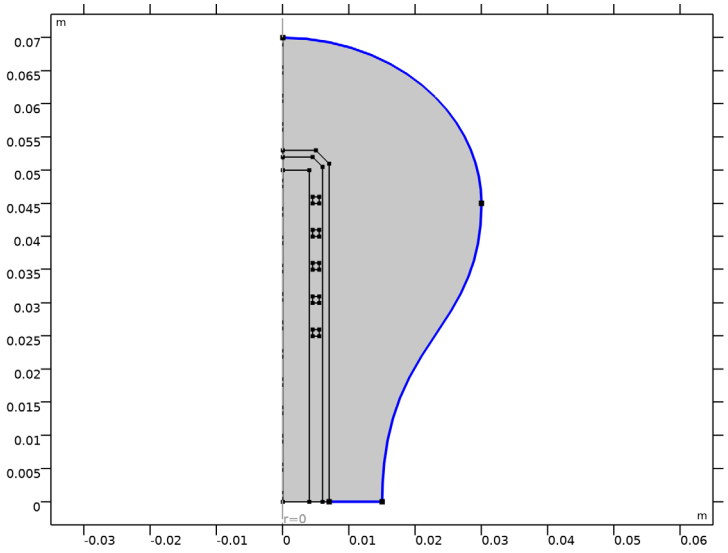
4 Locate the **Element Size Parameters** section.

5 Select the **Maximum element size** check box. In the associated text field, type `5e-4`.

Edge 3

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

2 Select Boundaries 36–38 only.



Size 1

1 Right-click **Edge 3** 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** check box. In the associated text field, type `1e-3`.

Boundary Layers 1

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

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

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

4 Select Domain 4 only.

5 Click to expand the **Transition** section. Clear the **Smooth transition to interior mesh** check box.

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 **Boundary layers**.

4 Locate the **Layers** section. In the **Stretching factor** text field, type `1.1`.

5 From the **Thickness specification** list, choose **First layer**.

6 In the **Thickness** text field, type `2E-5`.

Free Triangular 1

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

2 In the **Settings** window for **Free Triangular**, click  **Build All**.

STUDY 1

Step 1: Frequency-Transient

1 In the **Model Builder** window, under **Study 1** click **Step 1: Frequency-Transient**.

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

3 In the **Frequency** text field, type `2[MHz]`.

4 In the **Output times** text field, type `0`.

5 Click  **Range**.

6 In the **Range** dialog box, choose **Number of values** from the **Entry method** list.

7 In the **Start** text field, type `-8`.

8 In the **Stop** text field, type `log10(2e-3)`.

9 In the **Number of values** text field, type `3`.

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

11 Click **Add**.

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

RESULTS

Power Deposition

1 In the **Home** toolbar, click  **Add Plot Group** and choose **2D Plot Group**.

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

Surface 1

1 Right-click **Power Deposition** and choose **Surface**.

2 In the **Settings** window for **Surface**, click **Replace Expression** in the upper-right corner of the **Expression** section. From the menu, choose **Component 1 (comp1)>Magnetic Fields> Heating and losses>mf.Qrh - Volumetric loss density, electric - W/m³**.

3 Locate the **Coloring and Style** section. Click **Change Color Table**.

4 In the **Color Table** dialog box, select **Thermal>ThermalWave** in the tree.

5 Click **OK**.

Selection 1

1 Right-click **Surface 1** and choose **Selection**.

2 Select Domain 4 only.

3 In the **Power Deposition** toolbar, click **Plot**.

Ground State Mercury Mole Fraction

1 In the **Home** toolbar, click **Add Plot Group** and choose **2D Plot Group**.

2 In the **Settings** window for **2D Plot Group**, type `Ground State Mercury Mole Fraction` in the **Label** text field.

Surface 1

1 Right-click **Ground State Mercury Mole Fraction** and choose **Surface**.

2 In the **Settings** window for **Surface**, click **Replace Expression** in the upper-right corner of the **Expression** section. From the menu, choose **Component 1 (comp1)>Plasma> Mole fractions>plas.x_wHg - Mole fraction - 1**.

3 In the **Ground State Mercury Mole Fraction** toolbar, click **Plot**.

Mercury Ion Number Density

1 In the **Home** toolbar, click **Add Plot Group** and choose **2D Plot Group**.

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

Surface 1

1 Right-click **Mercury Ion Number Density** and choose **Surface**.

2 In the **Settings** window for **Surface**, click **Replace Expression** in the upper-right corner of the **Expression** section. From the menu, choose **Component 1 (comp1)>Plasma> Number densities>plas.n_wHg_1p - Number density - 1/m³**.

3 In the **Mercury Ion Number Density** toolbar, click **Plot**.

Mole Fraction of Excited Mercury 2

1 In the **Home** toolbar, click **Add Plot Group** and choose **2D Plot Group**.

2 In the **Settings** window for **2D Plot Group**, type `Mole Fraction of Excited Mercury 2` in the **Label** text field.

Surface 1

1 Right-click **Mole Fraction of Excited Mercury 2** and choose **Surface**.

2 In the **Settings** window for **Surface**, click **Replace Expression** in the upper-right corner of the **Expression** section. From the menu, choose **Component 1 (comp1)>Plasma> Mole fractions>plas.x_wHg2 - Mole fraction - 1**.

3 In the **Mole Fraction of Excited Mercury 2** toolbar, click **Plot**.

Mole Fraction of Excited Mercury 4

1 In the **Home** toolbar, click **Add Plot Group** and choose **2D Plot Group**.

2 In the **Settings** window for **2D Plot Group**, type `Mole Fraction of Excited Mercury 4` in the **Label** text field.

Surface 1

1 Right-click **Mole Fraction of Excited Mercury 4** and choose **Surface**.

2 In the **Settings** window for **Surface**, click **Replace Expression** in the upper-right corner of the **Expression** section. From the menu, choose **Component 1 (comp1)>Plasma> Mole fractions>plas.x_wHg4 - Mole fraction - 1**.

3 In the **Mole Fraction of Excited Mercury 4** toolbar, click **Plot**.