Two-dimensional Numerical Simulation of a Planar Radio-Frequency Atmospheric Pressure Plasma Source

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Introduction:
The radio-frequency (RF) plasma sources have shown great potential in various industrial applications such as thin coatings deposition and polymers modification[1-2]. An RF atmospheric pressure planar helium discharge is studied through a two-dimensional (2D) COMSOL simulation with a capacitively coupled plasma module. Figure 1 shows the plasma source geometry structure and figure 2 represents the simulation model.

Figure 1. (a) Plasma source geometry and (b) Model in COMSOL

Computational Methods:
Capacitively Coupled Plasma Interface in COMSOL Multiphysics®

- Electrostatic Field: Poisson equation
- Electron Transport: continuity equation and drift diffusion equation
- Heavy Species Transport: Maxwell-Stefan equation
- Boundary Conditions: metal contact and dielectric contact
- Initial Conditions:
  - \( n_{e0} = 10^{17} \text{ m}^{-3} \)
  - \( T_e = 273.15 \text{K} \)
  - \( P = 1 \text{ atm} \)
  - \( \varepsilon_e = 10 \)
- Plasma Chemistry: cross section data are mainly calculated from BOLSIG+

Table 1. Reactions included in simulation.

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Rate(m³/s)</th>
<th>Types</th>
</tr>
</thead>
<tbody>
<tr>
<td>e+He \rightarrow e+He</td>
<td>( f(T_e) )</td>
<td>Elastic Collision</td>
</tr>
<tr>
<td>e+He \rightarrow e+Hes</td>
<td>( f(T_e) )</td>
<td>Excitation</td>
</tr>
<tr>
<td>e+Hes \rightarrow e+He</td>
<td>( f(T_e) )</td>
<td>De-excitation</td>
</tr>
<tr>
<td>e+He \rightarrow 2e+He^+</td>
<td>( f(T_e) )</td>
<td>Ionization</td>
</tr>
<tr>
<td>e+He^+ \rightarrow Hes</td>
<td>( 6.76 \times 10^{-19} T_e^{-0.5} )</td>
<td>Recombination</td>
</tr>
<tr>
<td>Hes+Hes \rightarrow e+He_2^+</td>
<td>( 1.4 \times 10^{31} (T_e/300)^{-0.5} )</td>
<td>Associative Ionization</td>
</tr>
</tbody>
</table>

Results:
Figure 2, 3, 4 indicate that \( n_e, T_e, T_i \) variation follow the RF cycle, while \( n_i \) distribution remains almost the same with time. The \( n_e \) and \( n_i \) range from \( 1.8 \times 10^{17} \text{ m}^{-3} \) to \( 2.0 \times 10^{17} \text{ m}^{-3} \) in the plasma bulk. Figure 4 also suggests that ion temperature increases to 0.9 in the sheath region where ions are accelerated towards the wall.

![Figure 2](image-url)  ![Figure 3](image-url)  ![Figure 4](image-url)

Conclusions:
Relatively high ion temperature gives the source potential to be used in coatings and depositions on polymers. Physics of the discharge obtained through COMSOL 2D simulation can provide detailed insights in the discharge operation.

References: