

Simulation of Nitrogen Contaminated Ceramic Metal Halide Lamps

Finite Element Method Simulation

Péter Juhász Szabolcs Beleznai

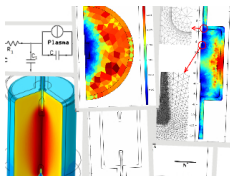


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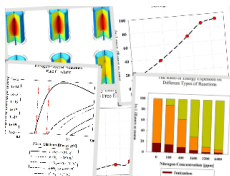
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2023. november 16.

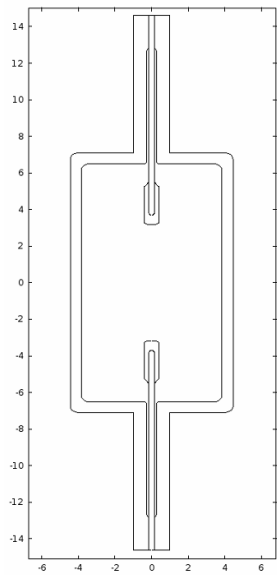
- Model



- Results

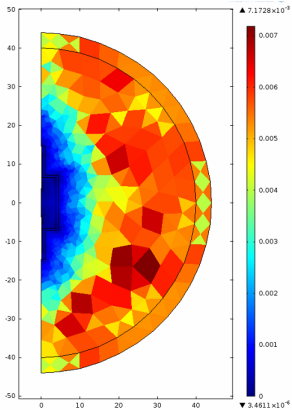


- Conclusion

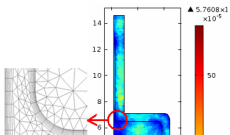


- Argon
- Nitrogen
- Silicon Carbide
- Air

Mesh Properties



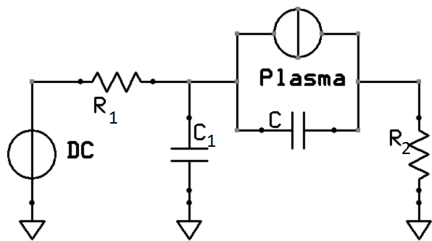
Lamp and Environment



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- Extremely fine mesh forced around electrodes
- Boundary layers
- Mesh independency verified – three different meshes

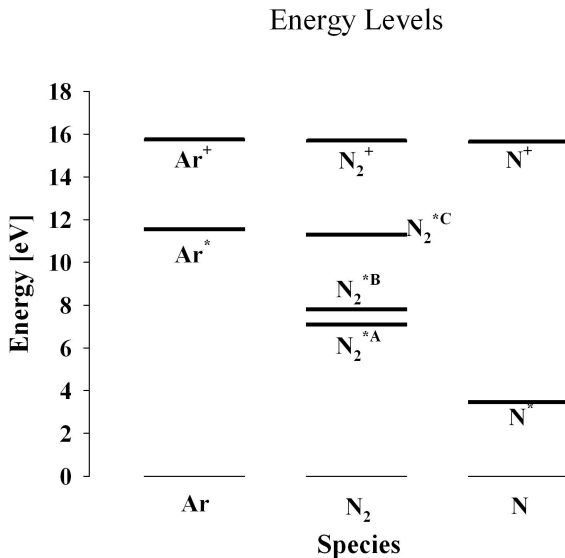
Electrical Circuit Model



- $U_{DC} = 800V$
- $R_1 = 5000\Omega$
- $C_1 = 10^{-10}F$
- $R_2 = 10000\Omega$

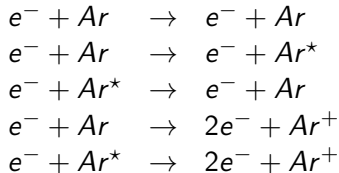
e^-	electron	N	atomic nitrogen – normal
Ar	argon – normal	N^*	atomic nitrogen – excited
Ar^*	argon – excited	N^+	atomic nitrogen – ionized
Ar^+	argon – ionized	Ar	molecular nitrogen – normal
		N_2^*A	molecular nitrogen – excited
		N_2^*B	molecular nitrogen – excited
		N_2^*C	molecular nitrogen – excited
		N_2^+	molecular nitrogen – ionized

Simulated Energy Levels of Different Species

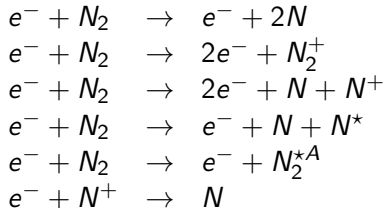


Electron Impact Reactions

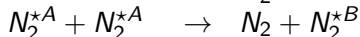
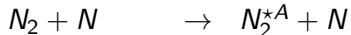
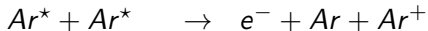
Electron Impact Argon Reactions



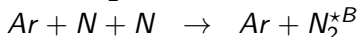
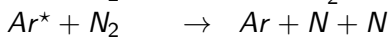
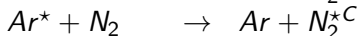
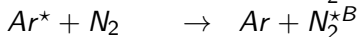
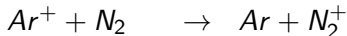
Electron Impact Nitrogen Reactions



Argon–Argon and Nitrogen–Nitrogen Reactions



Argon–Nitrogen Reactions

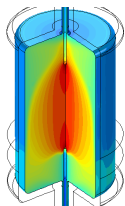


Process of Breakdown

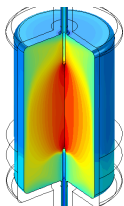
Definiton of breakdown
time: current reaches
10 mA on both electrodes.

This short video visualizes
the growth of the electron
density up to 60 μ s at a
nitrogen concentration of
1600 ppm.

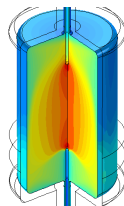
Electron Density at $4,2 \mu\text{s}$ vs. N_2 Concentration



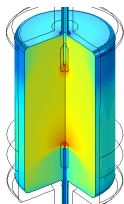
0 ppm



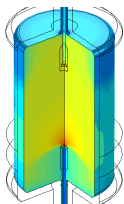
100 ppm



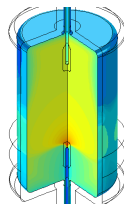
400 ppm



1600 ppm

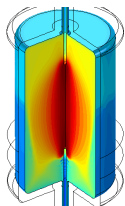


3200 ppm

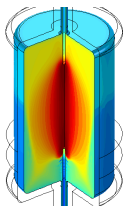


6400 ppm

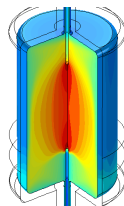
Electron Density at 5, 6 μs vs. N_2 Concentration



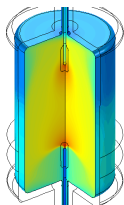
0 ppm



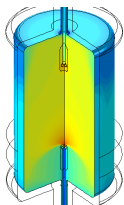
100 ppm



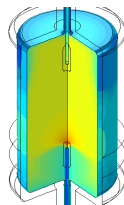
400 ppm



1600 ppm

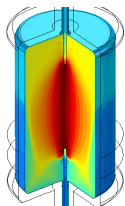


3200 ppm

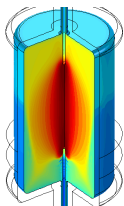


6400 ppm

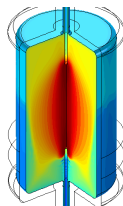
Electron Density at $17,8 \mu\text{s}$ vs. N_2 Concentration



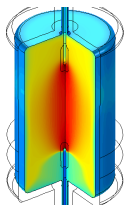
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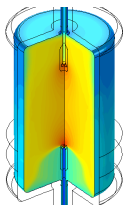
100 ppm



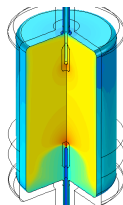
400 ppm



1600 ppm

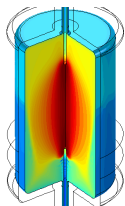


3200 ppm

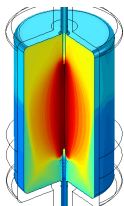


6400 ppm

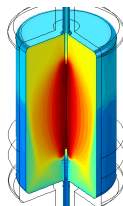
Electron Density at 57,4 μs vs. N_2 Concentration



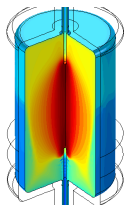
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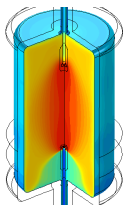
100 ppm



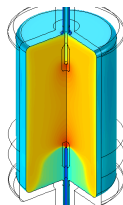
400 ppm



1600 ppm

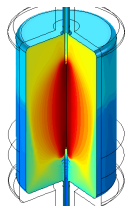


3200 ppm

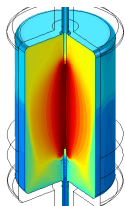


6400 ppm

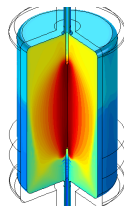
Electron Density at $189,2 \mu\text{s}$ vs. N_2 Concentration



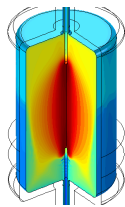
0 ppm



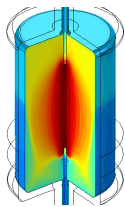
100 ppm



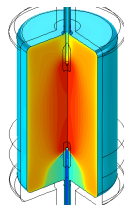
400 ppm



1600 ppm

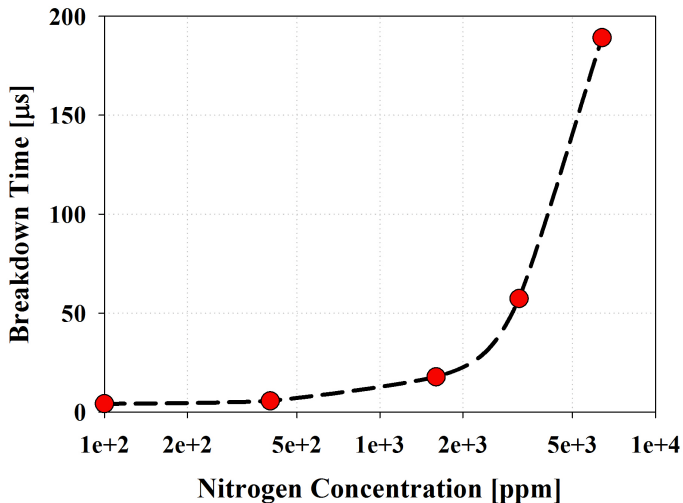


3200 ppm



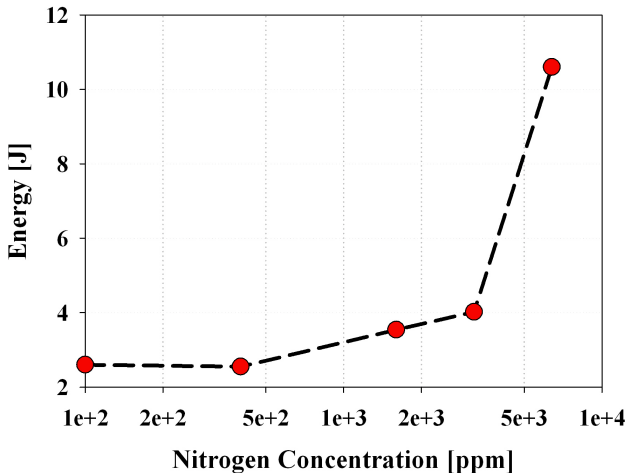
6400 ppm

Breakdown Time vs. Nitrogen Concentration

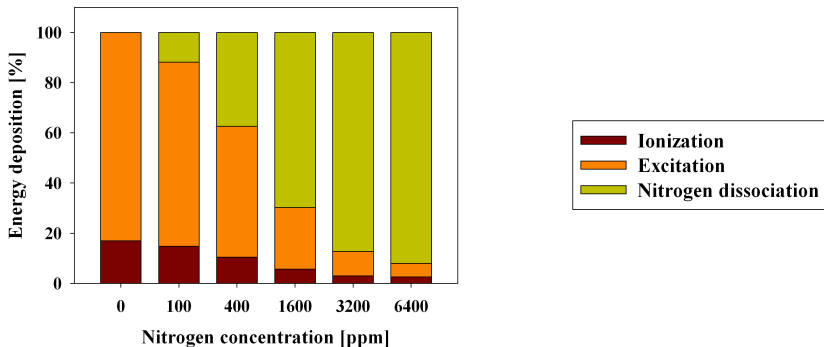


Essential Energy for Creating Free Electrons

Necessary Energy for
1 Coulomb Free Electrons



Energy Spent on Different Types of Reactions

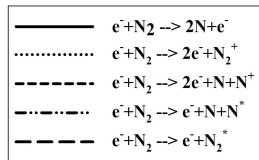
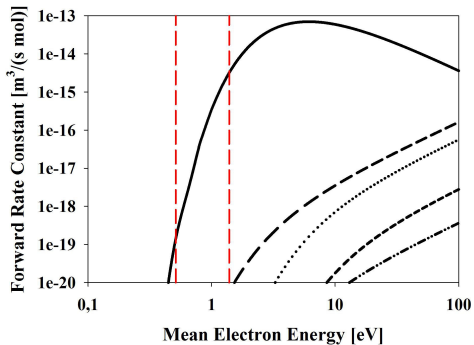


Contribution of Different Types of Nitrogen Dissociation

Reaction	Energy Ratio
$e^- + N_2 \longrightarrow e^- + 2N$	~ 1
$e^- + N_2 \longrightarrow 2e^- + N + N^+$	$\sim 10^{-11}$
$e^- + N_2 \longrightarrow e^- + N + N^*$	$\sim 10^{-11}$

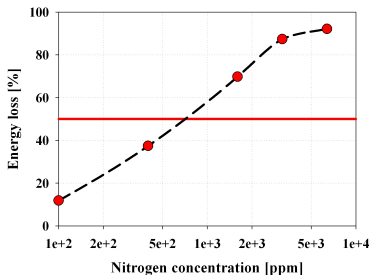
Forward Rate Constants

Nitrogen-Electron Reactions'
Rate Constants

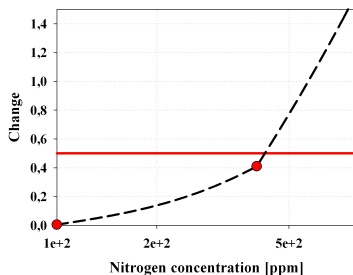


Effect of Contamination

Ratio of the energy loss caused
by nitrogen dissociation



Relative Change of Breakdown Time



The critical nitrogen concentration is about 500 ppm.

Thank you for your attention!