ALTASIM TECHNOLOGIES
REALIZING TOMORROW'S TECHNOLOGY

Simulation of Atmospheric Air Micro Plasma Jet for Biomedical Applications

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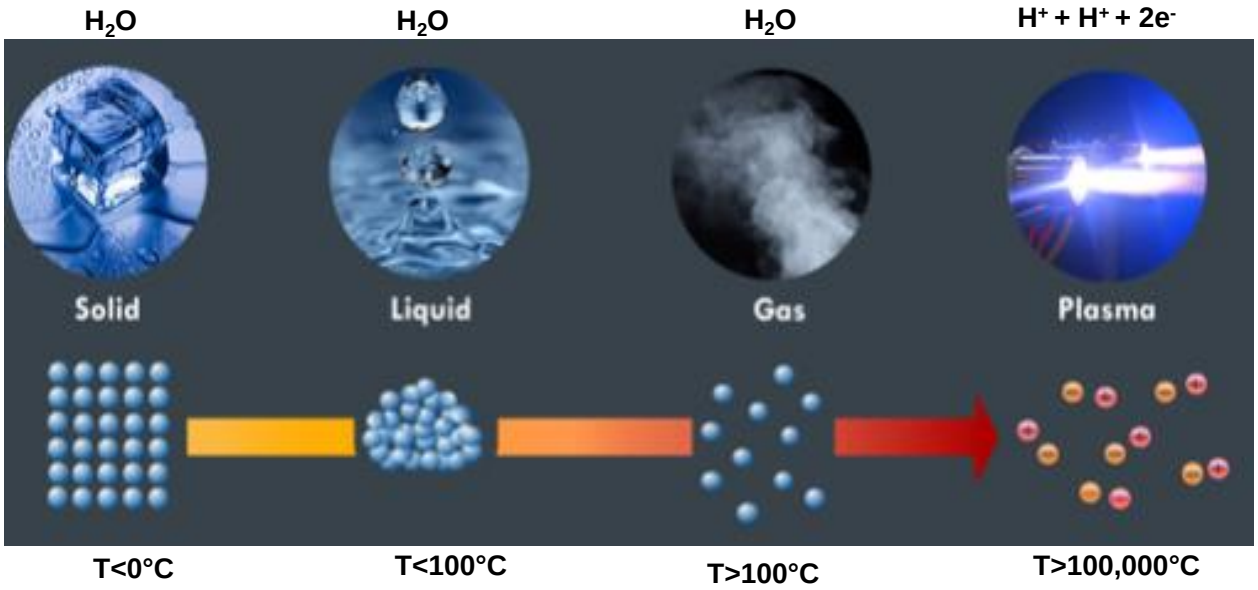
AltaSim Technologies

COMSOL Certified Consultant

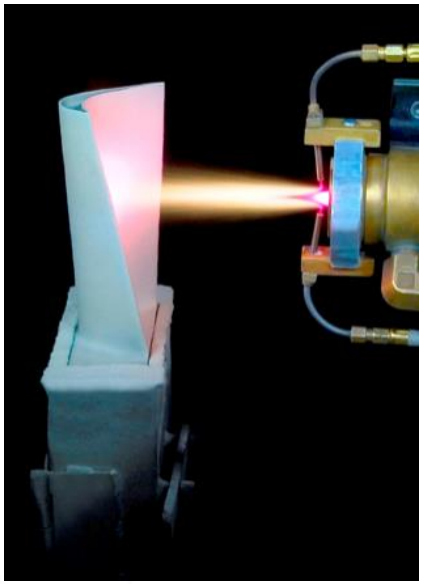
Plasma



- **Fourth state of matter**
  - **Conductive assembly of electrons, ions and neutral species**
  - **Overall quasi neutral**
- **Most common matter in the Universe**
- **Not naturally occurring on Earth**

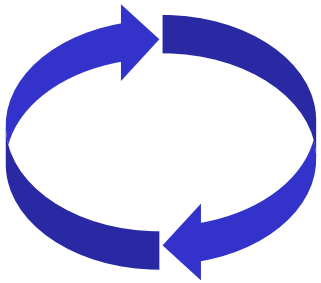
Plasma

- Spectroscopy
- Electronic devices
- Power systems



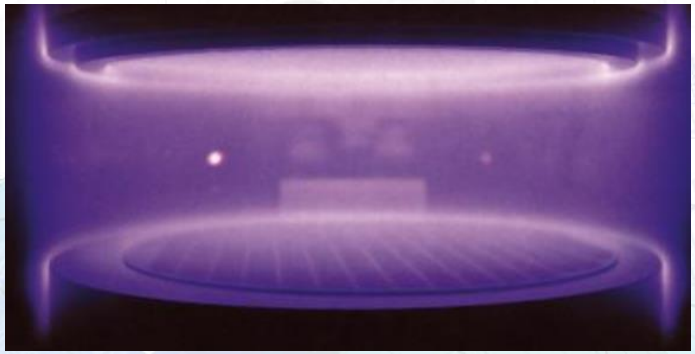
Displays
Lighting

Materials
Coatings



Electronic
devices

Semiconductor
devices/fabrication



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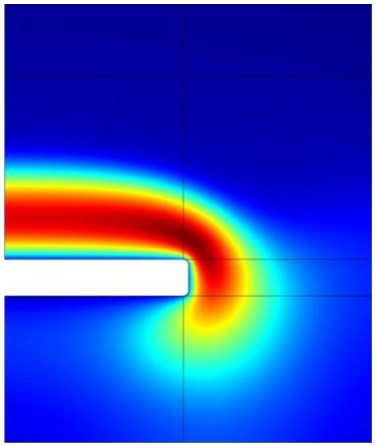
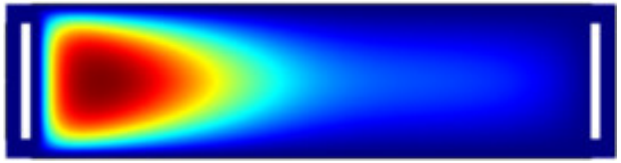
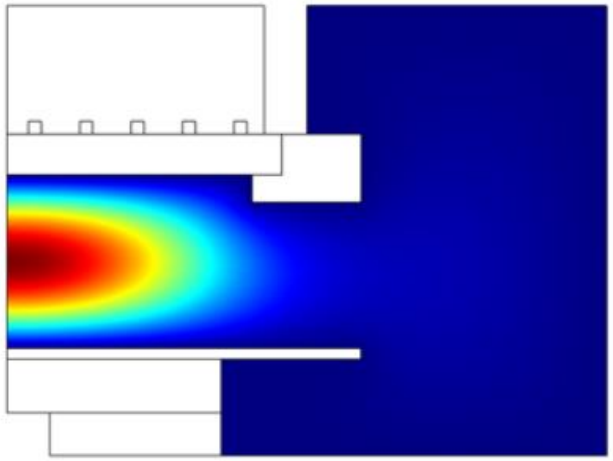
Plasma analysis



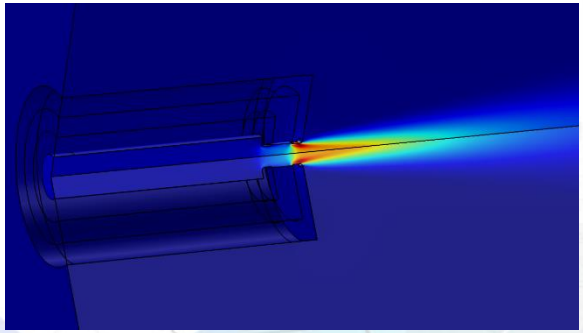
Capacitively coupled



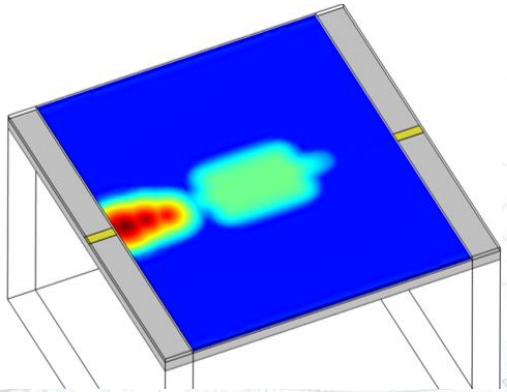
DC plasma



Inductively coupled



Plasma torch



Microwave

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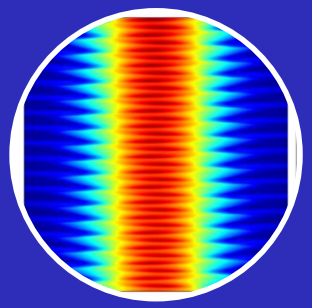
Simulation of plasmas



Fluid

Continuum

Solve transport equations

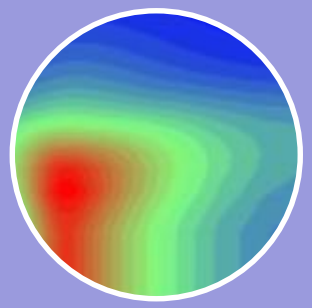
Assumed EEDF

Kinetic

Particle based

Distribution of velocities

Computer intensive



Hybrid

Mixed kinetic/fluid approach

Particle + mesh based PDEs

Plasma simulation methodologies

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Fluid approach to simulate plasmas

- **Electron density transport:**

$$\frac{\partial n_e}{\partial t} + \nabla \cdot \mathbf{\Gamma}_e = R_e - (\mathbf{u} \cdot \nabla) n_\varepsilon$$

4+ PDEs

- **Electron energy density transport:**

$$\frac{\partial n_\varepsilon}{\partial t} + \nabla \cdot \mathbf{\Gamma}_\varepsilon + \mathbf{E} \cdot \mathbf{\Gamma}_e = S_{en} - (\mathbf{u} \cdot \nabla) n_\varepsilon + \frac{Q + Q_{gen}}{q}$$

- **Heavy species transport (one for each species):**

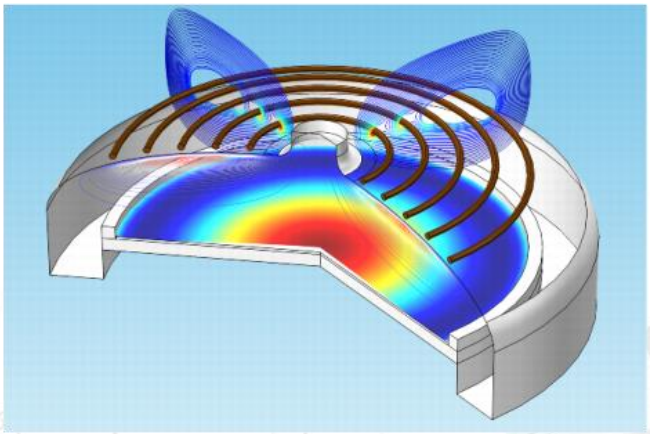
$$\rho \frac{\partial w_i}{\partial t} + \rho (\mathbf{u} \cdot \nabla) w_i = \nabla \cdot \mathbf{j}_i + R_i$$

- **Poisson's equation for electrostatics:**

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

Fluid approach advantages/limitations

- **Suitable for FEM**
- **Less computationally intensive**
- **Good approximation of many industrial plasmas**



PECVD ✓

Limitations

- $\frac{|\mathbf{E}|}{N} <$ ~ 500 Td
- $n_e << N$
- $\lambda_e << L$
- $p >$ ~ 1 mTorr

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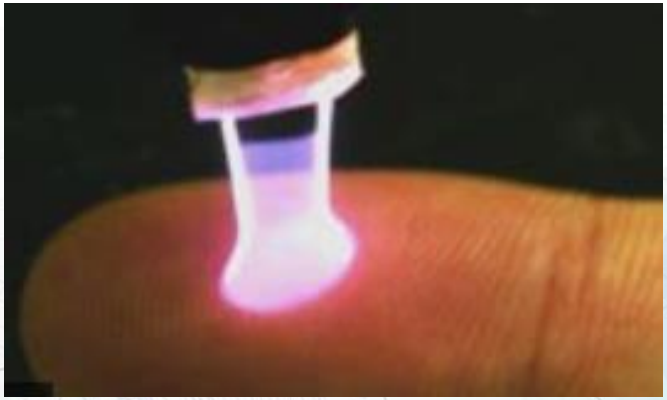
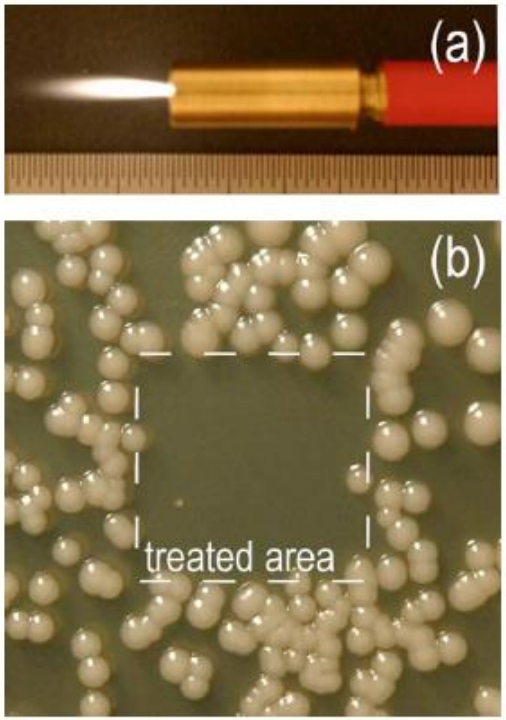
Plasma: Surface Cleaning

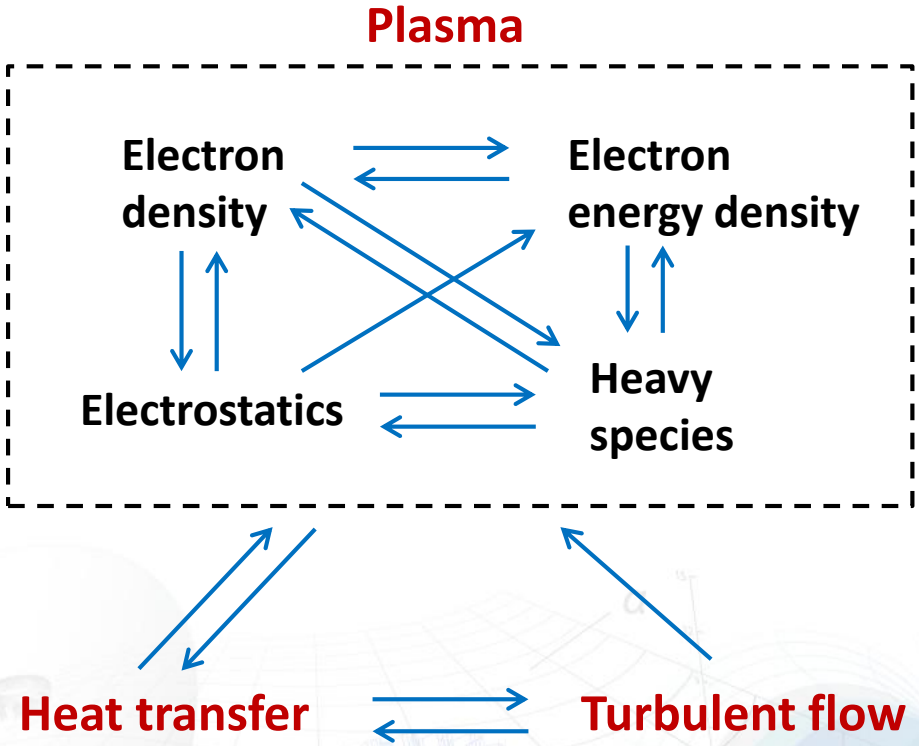
- Application: Medical, Food
- Environmentally benign compared to conventional:
  - Thermal
  - Chemical
- Low heat plasma operates in seconds/minutes
- Reaction between plasma free radicals and surface
- Bacteria, fungi, spores



DC micro plasma jet



Kolb, J. F., et al. Applied Physics Letters **92**, 1-3 (2008)



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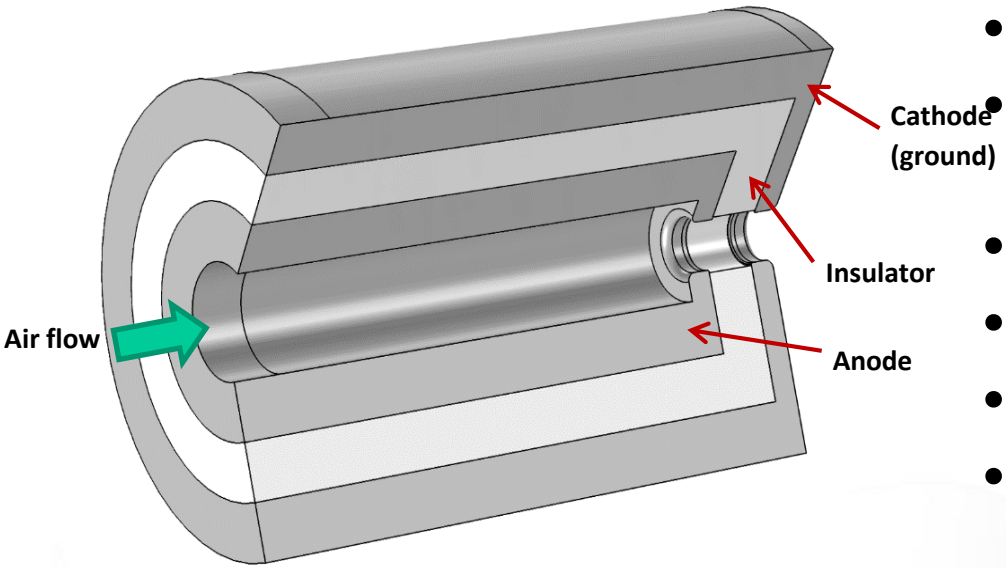
DC micro plasma jet

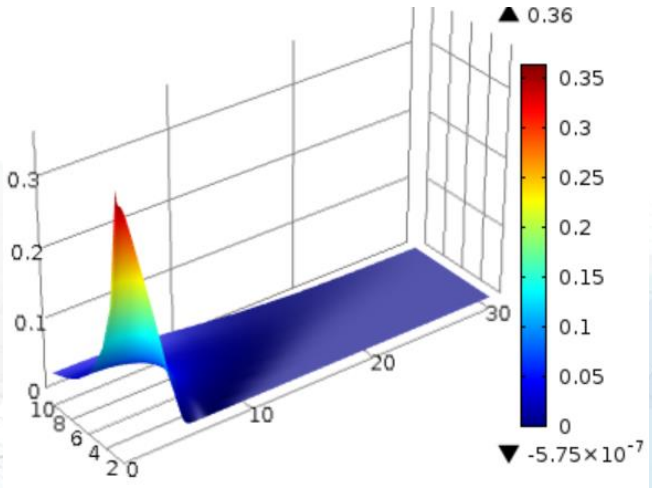


- 1 atm pressure
- Dry air (~ 80 % N_2 and 20 % O_2)
- Flow rate of air: 80 ml/min (at 20 °C)
- 100 kΩ ballast resistor
- 1000 V applied voltage
- Electrode voltage of 550 V
- Discharge current of 4.5 mA

Plasma analysis

- **Preprocessing**
  - **Two term Boltzmann equation**
  - **Distribution function in 6-dimensional phase space**
  - **Electron transport as function of electron energy**
    - *Electron density*
    - *Electron energy*
    - *Reaction rates*
    - *Transport coefficients*

- **Multiphysics analysis**
  - **Fluid/Reaction**
  - **Heat Transfer**
  - **Turbulent fluid flow**



Boltzmann EEDF

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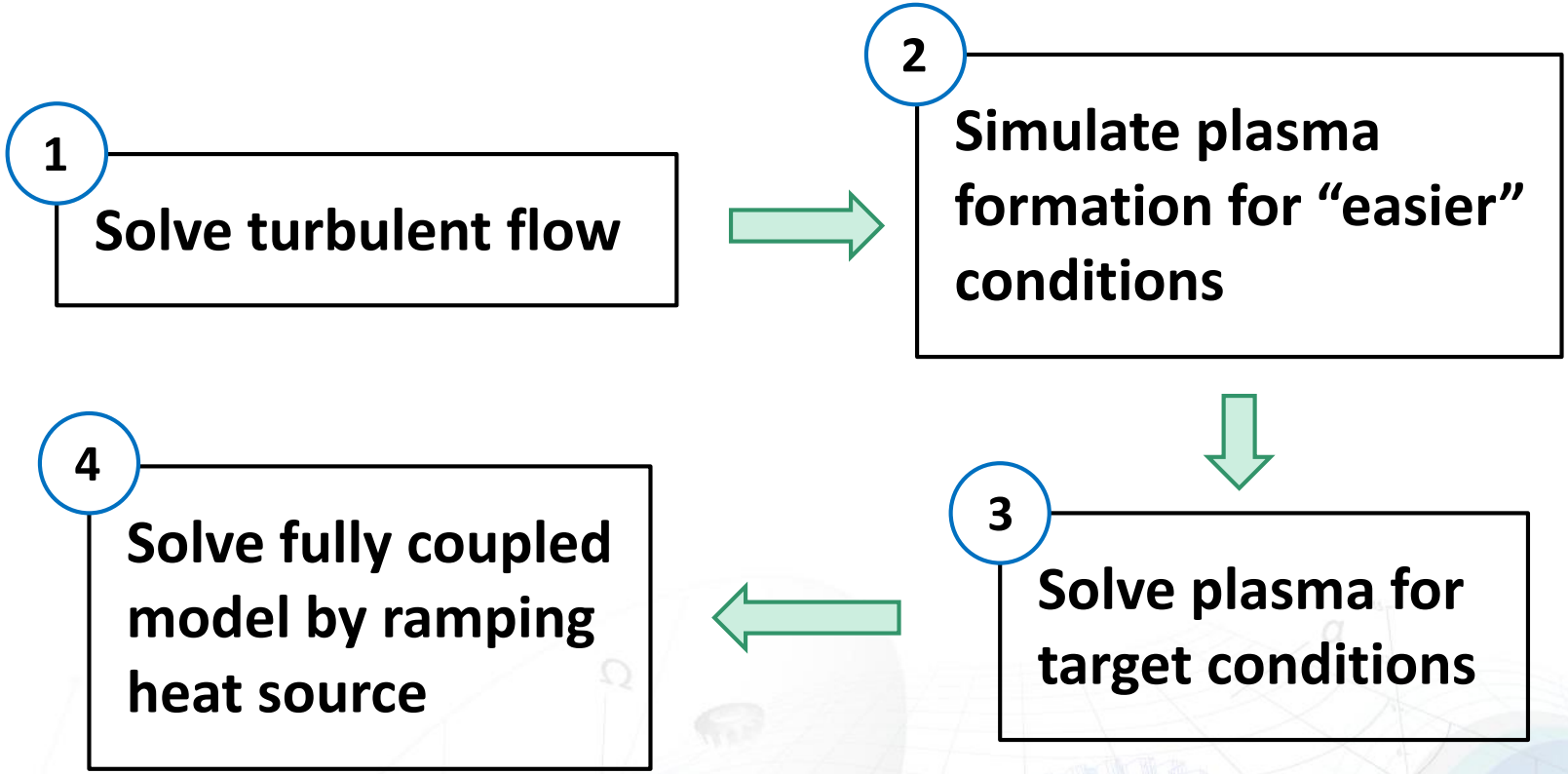
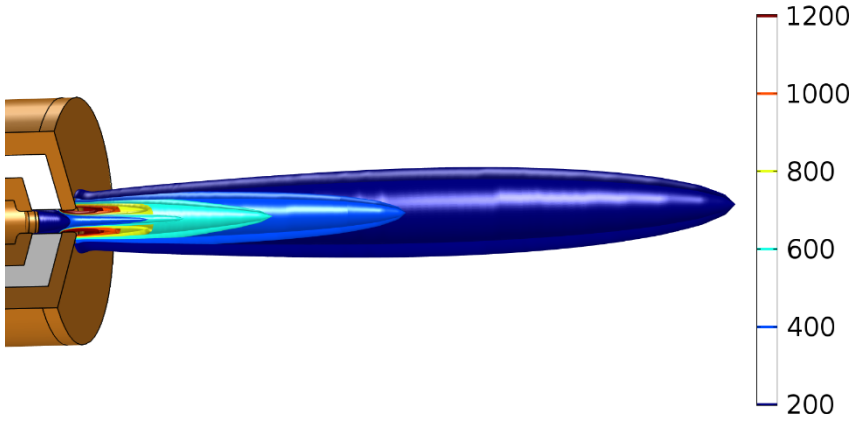
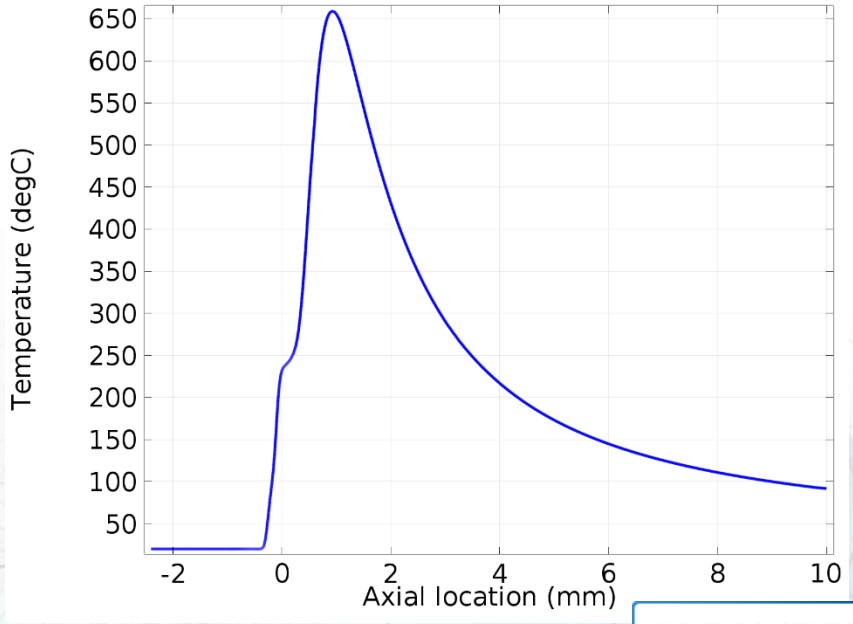
Multi-step solution methodology



Results: Temperature

- Peak temperature ~ 1900°C
- Maximum in cathode sheath
- Centerline temperature ~92°C 10mm from exit





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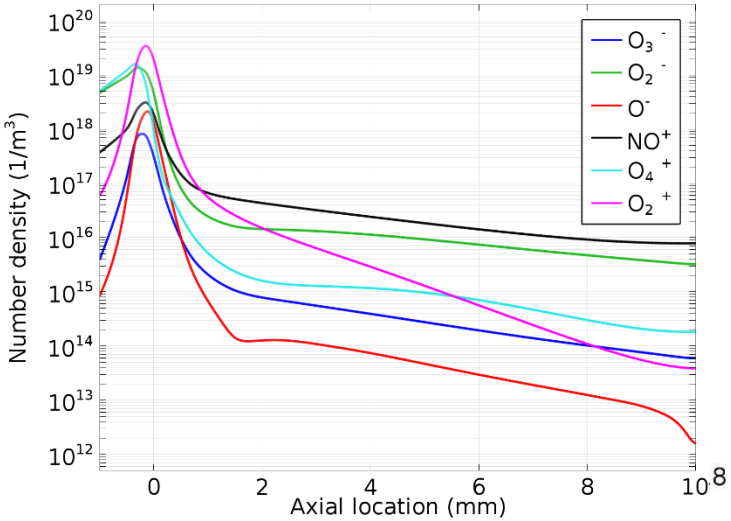
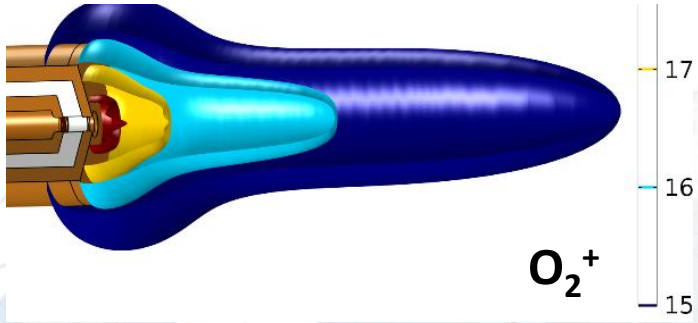
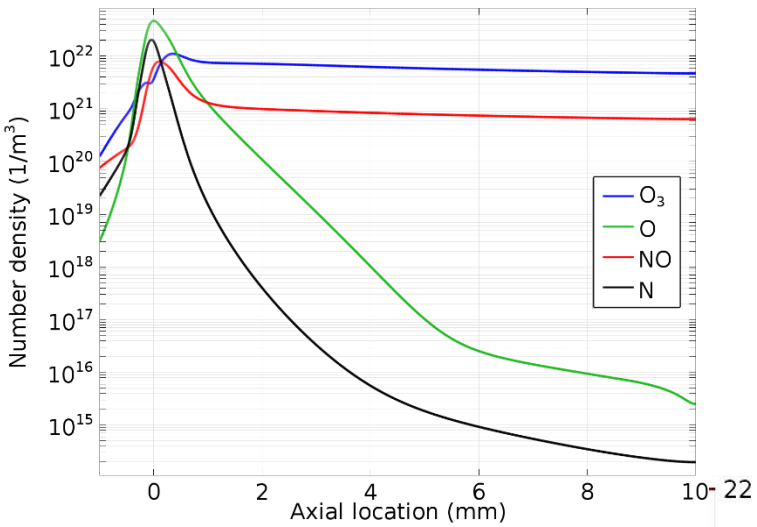
Results: Species

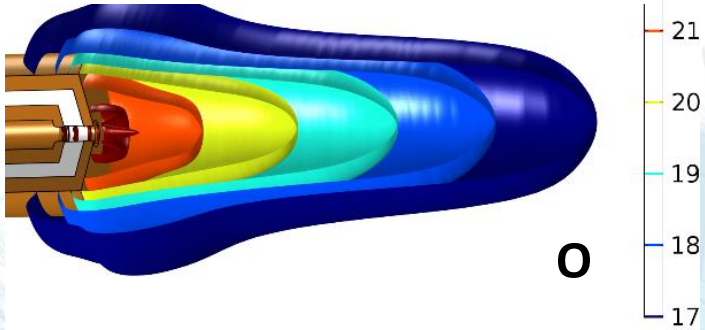
- **Reactive**





- **Neutral**





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Summary

- Plasma simulation of plasma jet
- Predicts distribution of:
  - Temperature
  - Species concentration
- Development and design of operating procedures