Problem Statement
A newly introduced, capacitively coupled, VHF remote plasma source has demonstrated unique functionality, warranting improved understanding. Empirically derived evaluation imposes practical limits to comprehensive characterization. Discretized simulation methods have been used previously to optimize the mechanical and electrical performance of the plasma source. Multi-physics simulation methods are now being used to characterize the plasma performance of the device.

Objective
Generate and validate multi-physics simulation tools which allow for a complete characterization of the plasma source.

Unique simulation challenges, relative to typical CCP reactors
- Operation at VHF (MHz) frequency
- Non-trivial, capacitive geometry
- Asymmetric electrode structure
- Broad-pitching space
- Remote application – need to predict downstream effects

Background
A Remote Plasma Source (RPS) is a plasma-generating device (source) which is isolated entirely from the process chamber.

- An RPS can introduce a predictable stream of radicals to the substrate, while minimizing damage from higher energy ions and electrons which are prevalent in the active discharge.
- The anode structure is inductively coupled plasma (ICP) chamber, often toroidal in design.
- Conventional applications for remote plasma sources include: chamber clean, process chamber without depositions, etching, or milling processes.
- Recent years, RPS technologies are demonstrating advantage in a wider scope of applications: radical generation for direct processing, low energy processing, and augmentation or replacement of off-site sources.

Previous Simulations
- Albany Rotating Disc Electrode (ARDE) simulations were used to enhance the spatial and temporal resolution of the device, and optimize the performance of the plasma plasma.
- Computational fluid dynamics (CFD) was used to optimize feed-gas delivery in the chamber.
- Numerical methods were used to model pressure, reactant distribution, and chemical reactions as a function of device configuration.

Conclusions
- Plasma density magnitude and its relationship with power correlate well with empirical data.
- Plasma density gradients (relationship with position) show a disparity with empirical data, and warrant further study.
- The simulations are accurately predicting the relationship between plasma density and power, as well as plasma density and pressure.

Future Work
- Continue to refine the simulations for Argon:
  - Achieve better correlation to empirical data, especially plasma distribution and position accuracy.
  - Enhance computing efficiency and reduce solve time.
  - Understand the impact of various simulation options:
    - Heat transfer & Stefan-Boltzmann heating
    - Low energy dielectric layers
    - Reactor- circuit coupling
    - Ion momentum.
- Explore other feed gas chemistries, including H2, O2, and NF3.
- Perform H2 radical output/ delivery optimization, parametric study.
- Use plasma simulation to optimize the geometry of future RPS designs.

Empirical Plasma Measurement
Langmuir Probe:
- Scientific Systems SmartProbe®
- Inserted axially into the output section of plasma source
- Measurements from 10–305 sccm spacing to powered electrode
- 4.5 cm increments
- Argon
  - Flow: 50 sccm
  - Pressure: 0.1, 0.5, and 1.0 Torr
  - Power: 50-300 W

Electron Energy Distribution Function (EEDF) Look-Up Tables
- The dependence of electron energy and transport coefficients on the non-Maxwellian EEDF is accounted for using look-up tables.
- Look-up tables are created from the numerical solution of the Boltzmann equation to create tabulated data that is imported into the multidimensional simulations.
- Reaction rate constants $\alpha$, diffusion coefficient $D$, and mobility of electrons are calculated from the EEDF.

Characterization and Simulation of a VHF Remote Plasma Source
Scott Polak, Dan Carter, Ananth Bhoj, Abhra Roy

CFD-ACE® Multi-Physics Solver
Comprehensive plasma simulation:
- Fluid dynamics
- Heat transfer
- Chemistry
- Electromagnetic
- Plasma
- Boltzmann / Kinetics

Plasma Equations:
- Poisson’s equation solved sequentially with charged species transport equations and surface charge
- Neutral transport equations are addressed
- The electron energy equations is solved for electron temperature, considering power deposition and collisional losses
- Electron Energy Distribution Function (EEDF) Look-Up Tables
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