Simulations of High-Pressure Cathodic Arcs with Adaptive Cartesian Mesh

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The development of advanced compuational techniques for low temperature plasmas is a continuing need as the complexity of the phenomena being investigated increases. In this regard, we have developed a computational tool for simulations of high-pressure arcs with an Adaptive Cartesian Mesh (ACM). The new tool has been validated against available experimental and simulation results for several types of arcs with external DC and AC magnetic fields at gas pressures from 1 to 100 atm. Good agreement has been found with available data for spatial distributions of gas temperature, arc motion by gas convection and magnetic fields, voltage drop, plasma jet velocities and Maecker jet pinch pressures [1].

We have investigated the effects of the cathode plasma jet on the structure of the anode arc spot observed in experiments [2]. With increasing distance between a rod cathode and a planar anode, constriction of the anode spot and a formation of an anode jet were observed in atmospheric pressure arcs. We have reproduced the main results of Ref. [2] with the ACM code using a simple model of the anode layer taking into account non-LTE effects. A gradual constriction of the anode spot and the formation of the anode jet with increasing inter-electrode gap was obtained in our simulations. Results for an inter-electrode gap of 30 mm are shown in Fig. 1. The structure of the anode arc spot is determined by the anode-jet (reverse) vortex flow, which runs in clockwise direction – tthe cathode vortex occurs in the counter-clockwise direction. This anode vortex brings cold gas into the arc column along the anode surface.

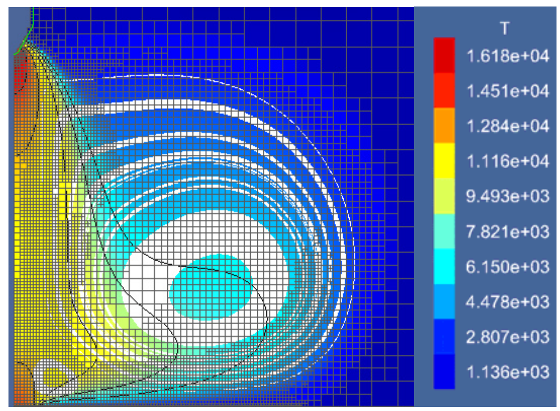


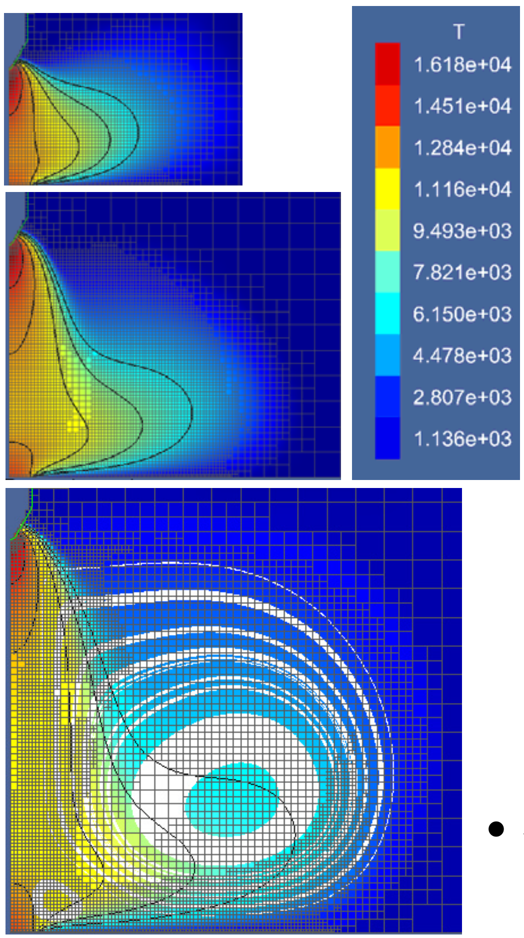
Figure 1 – Spatial distributions of gas temperature (K), adapted computational mesh, and flow streamlines in an arc discharge between a rod cathode and a planar anode illustrating anode jet formation in atmospheric pressure arc with inter-electrode gap of 30 mm.

Our studies indicated that Explosive Electron Emission (EEE) typical to vacuum arcs could also play an important role in high-pressure cathodic arcs. In a new DOE SBIR project [3], which has just started, we will clarify the specifics of EEE under different conditions. We will investigate near-electrode phenomena over a wide range of pressures to understand the effects of ambient gas pressures on the formation of explosive centers. We will develop multi-phase capabilities for simulations of EEE processes under different operating conditions.

References

[1] V Kolobov et al, "Computational model for electrode erosion by high-pressure moving arcs", Final Report for the AFOSR STTR Phase II Project FA9550-14-C-0026 (2016).
[2] Hi Taki et al, Vacuum **88** 42-26, (2013).
[3] V Kolobov et al, "Simulations of Explosive Electron Emission in Cathodic Arcs", DOE SBIR Phase I Project DE-SC0015746.

SIMULATIONS OF HIGH-PRESSURE CATHODIC ARCS WITH ADAPTIVE CARTESIAN MESH



- **We have developed a computational tool with an adaptive Cartesian mesh for simulations of high-pressure moving arcs.**
- **The new tool has been validated against available experimental and simulation data for arcs with external DC and AC magnetic fields at gas pressures from 1 to 100 atm.**
- **We have simulated effects of cathode plasma jet on the anode arc spot and obtained good agreement with experimental observations. Cathode jet affects on anode spot depends on gap size.**
- **New DOE SBIR project will clarify specifics of Explosive Electron Emission at the cathode surface.**

- **Spatial distributions of gas temperature (K) and adapted computational mesh for different inter-electrode gaps (10, 20 and 30 mm) illustrating anode jet formation at large gaps.**

Consequences of Lattice Orientation in Packed Bed Reactors

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Dielectric barrier discharges (DBDs) in packed bed reactors (PBRs) at atmospheric pressures are of interest for removal of toxic gases, CO_2 reprocessing, and gas conversion. A PBR consists of dielectric beads or pellets distributed between two electrodes. The applied electric field is intensified in the gas phase between the beads leading to higher rates of ionization and greater production of reactive species. We have computationally and experimentally investigated the manner in which atmospheric pressure discharges propagate through a lattice of dielectric rods in a 2-dimensional configuration.

Predicted electron density is shown in Fig. 1 for a 1-atm negative discharge through humid air (-30 kV) propagating through a lattice of 7 quartz rods. The primary modes of discharge propagation are positive streamers (restrikes), filamentary microdischarges (FMs) and surface ionization waves (SIWs). Positive restrikes formed following breakdown in regions of high electric field. In cases where restrikes were confined between two dielectric rods, the discharges developed into standing filamentary microdischarges. SIWs were the most intense types of discharges and produced the highest electron densities. They formed in regions where the applied electric field had components tangential to the surface of the dielectric rods, and so depends on the orientation of the lattice of dielectric beads. Experimental imaging of a 2-d PBR having optical access showed FM structures between rods, and SIWs along the surface of rods. The production of reactive species by electron impact occurs in distinct impulsive transients which correlated with the onset of difference discharge structures. The onset of SIWs resulted in the most impulsive production of reactive species.

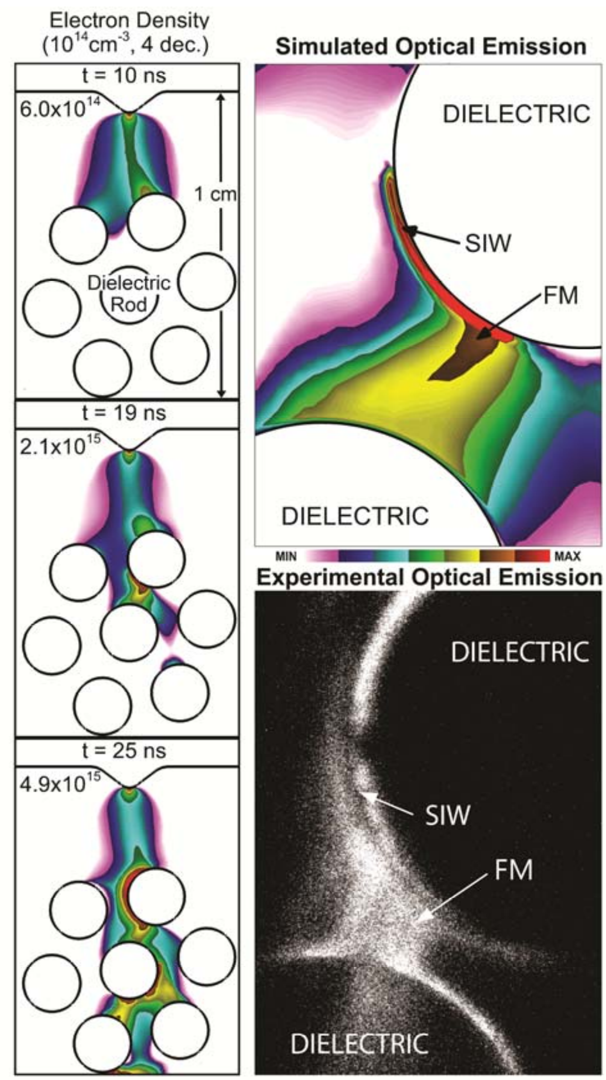
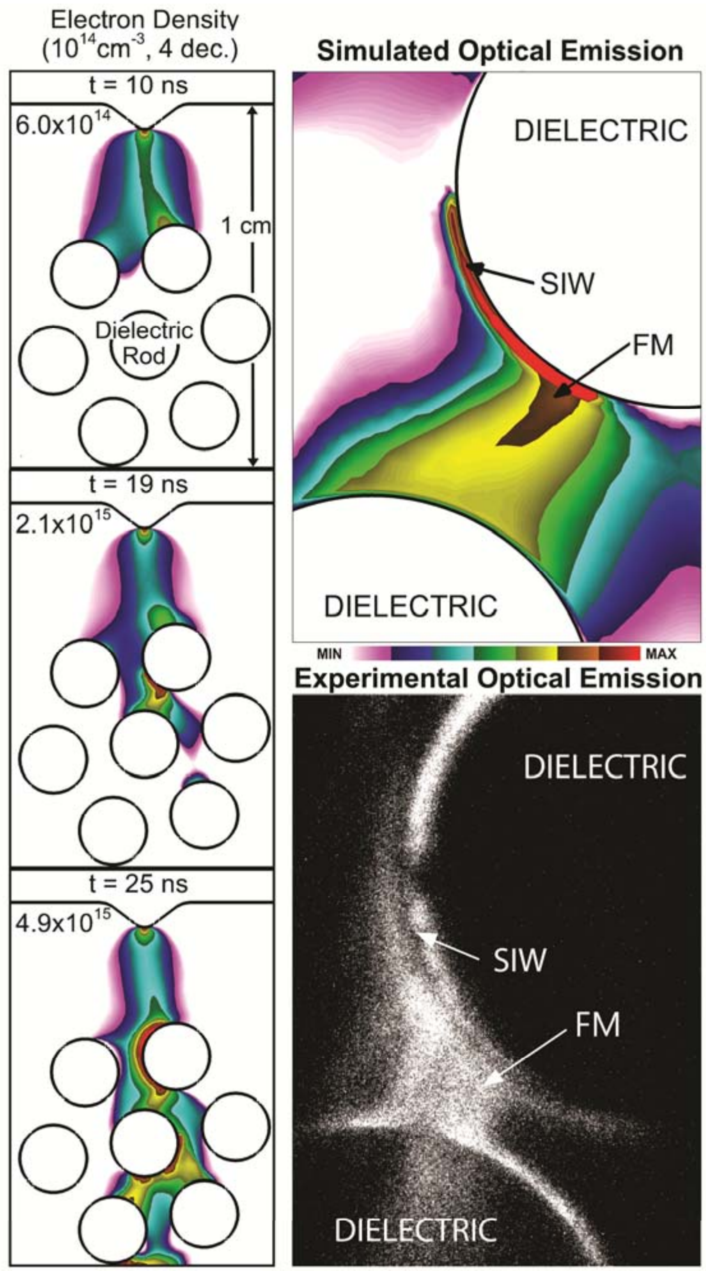


Figure 1 – Discharge propagation through a 2-d PBR. (left) Predicted electron density for a lattice dominated by filamentary microdischarges (FM) abd surface ionization waves (SIW). (right) Simulated and experimental optical emission showing connection between FM and SIW.

DISCHARGE MODES IN PACKED BED REACTORS



- **Plasmas in Packed Bed Reactors (PBRs) are used for atmospheric gas processing due to their efficiency for producing reactants.**
- **2-dimensional PBRs were computationally and experimentally investigated to determine modes of plasma transport.**
- **Depending on orientation of the dielectric lattice, discharges transition between positive restrikes, filamentary micro-discharges (FM) and surface ionization waves (SIW).**
- **The dominating mode depends on the orientation of the lattice, with SIWs produced when the applied electric field has tangential orientation to the rods in the lattice.**
- **Model and experimental results for electron density and optical emission demonstrate the transition between modes.**