LOW PRESSURE CASCADED ARC DISCHARGE

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Abstract

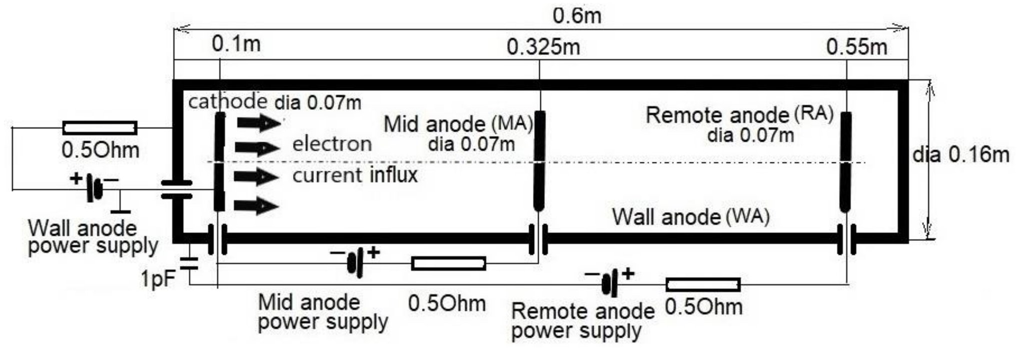
A remote arc plasma discharge [1] was ignited in the pressure range 1-25 mTorr in a rectangular chamber between a planar vacuum arc cathode with magnetic steering of the cathodic arc spots and a remote anode in the form of rectangular plate. An auxiliary mid anode in the form of a rectangular plate was positioned in the middle between the chevron baffle screen and the remote anode. The I-V characteristics of this discharge, obtained by modeling and experiment, have demonstrated that, in comparison to low pressure glow discharge, the electron emission mechanisms (thermionic emission vs. secondary emission), as well as boundary conditions on the discharge tube walls, strongly influence both the plasma distribution and the electrical characteristics of the discharge. It was found that the proximate mid anode can promote the ignition of the long remote arc discharge between the cathode and the distant remote anode.

[1] V.Gorokhovsky, P. Del Belluz, "Ion treatment by low pressure arc plasma immersion surface engineering processes," Surf. Coat. Tech., 215, 431-439 (2013).

Motivations

- Igniting a DC arc discharge at low pressures in large volumes allows for various applications in surface treatment, synthesis of nanopowders and electric propulsion.
- Using an intermediate anode for ignition and supporting long arc discharges via the cascade arc mechanism is considered as a way to conduct long arc discharge in large volumes.

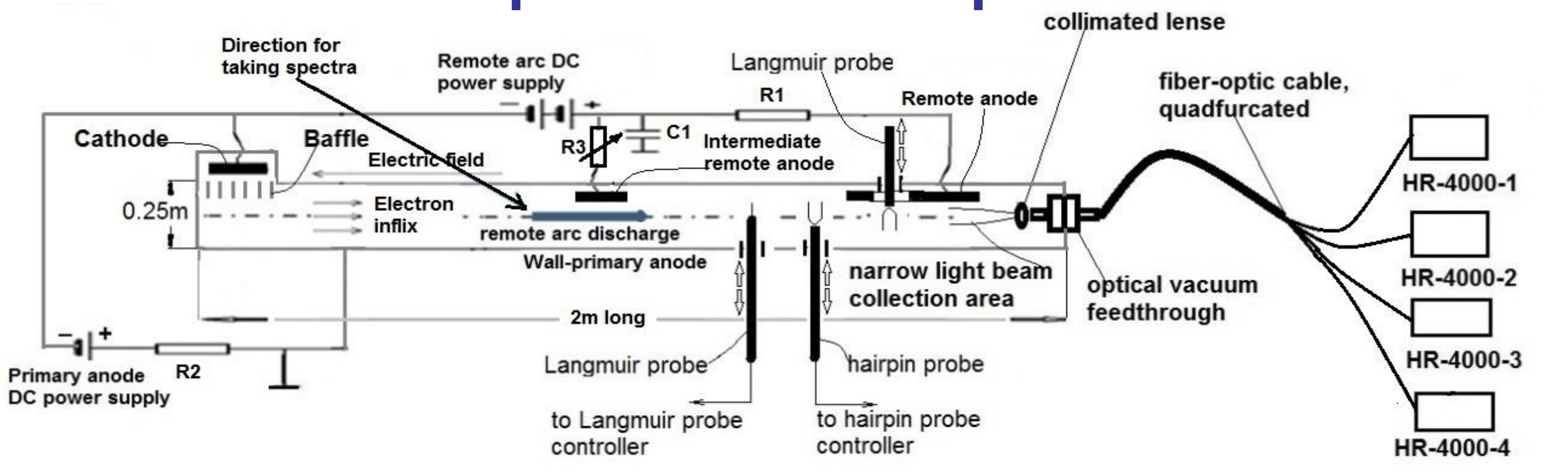
Drift-diffusion model



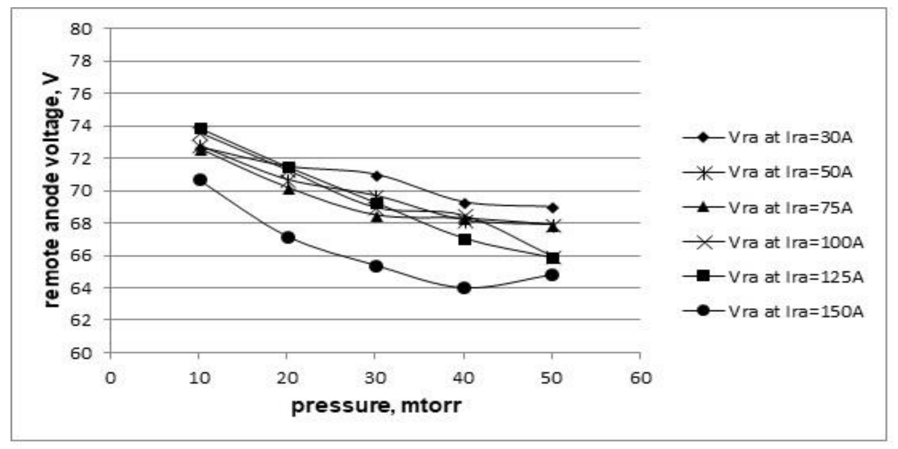
COMSOL Plasma Module was used for the modeling of the low pressure arc discharge [2,3]. The electron density and mean energy are computed by solving a pair of drift-diffusion equations using the Drift Diffusion Interface. Transport of heavy species is determined by solving a modified form of Maxwell-Stefan equations using The Heavy Species Transport Interface. The set of reactions, included in this model consists of Ar ionization, excitation, elastic scattering and surface neutralization. The Maxwellian electron energy distribution function is used for calculation of the cross-sections of the reactions in argon plasma. In the Plasma Module, a set of transport equations is coupled via DC Discharge Interface. Electric potential within the discharge tube is defined by solving a Poisson equation while the Electrical Circuit Interface is used to add an external electric circuit to the plasma model. The electron emission from the cathode was modeled by mimicking the thermionic emission in which the electron influx is provided as an input parameter of the model. The input voltages in the remote anode, mid anode and wall anode circuits were taken at 125V, 90V and 30V respectfully. It is shown that the ion current contribution at the cathode increases with increase of the total discharge current. The modeled I-Vs of the low pressure cascaded arc discharge have demonstrated the decrease of the anode voltages with increase of the current when the additional RA and MA anodes are added to the discharge tube interior, while wall anode voltage increases with increase of the current when additional internal anodes are absent. The modeling also demonstrated decrease of the plasma impedance both with increase of the total arc current and the pressure.

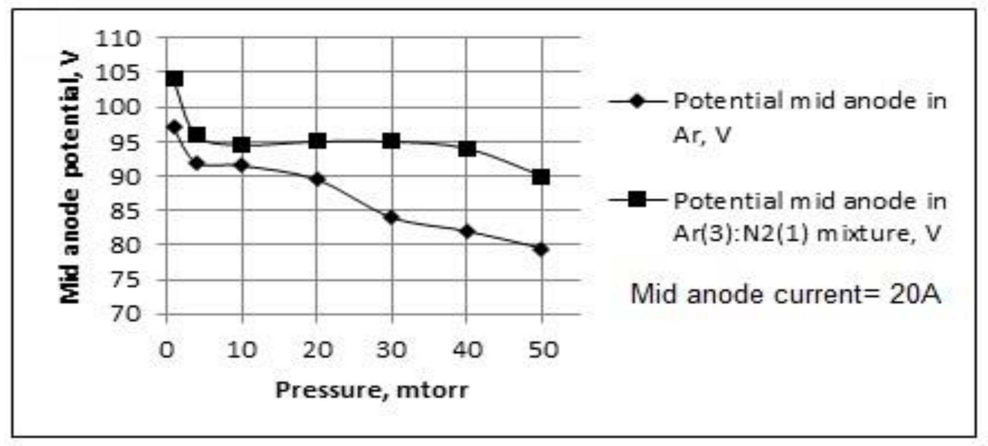
[2] V.Gorokhovsky, "Modeling of DC Discharges in Argon at Low Pressures", poster of the 12th COMSOL Conference, Boston, 2012.
[3] COMSOL Plasma Module User's Guide, 2017.

Experimental setup



Electrical characteristics

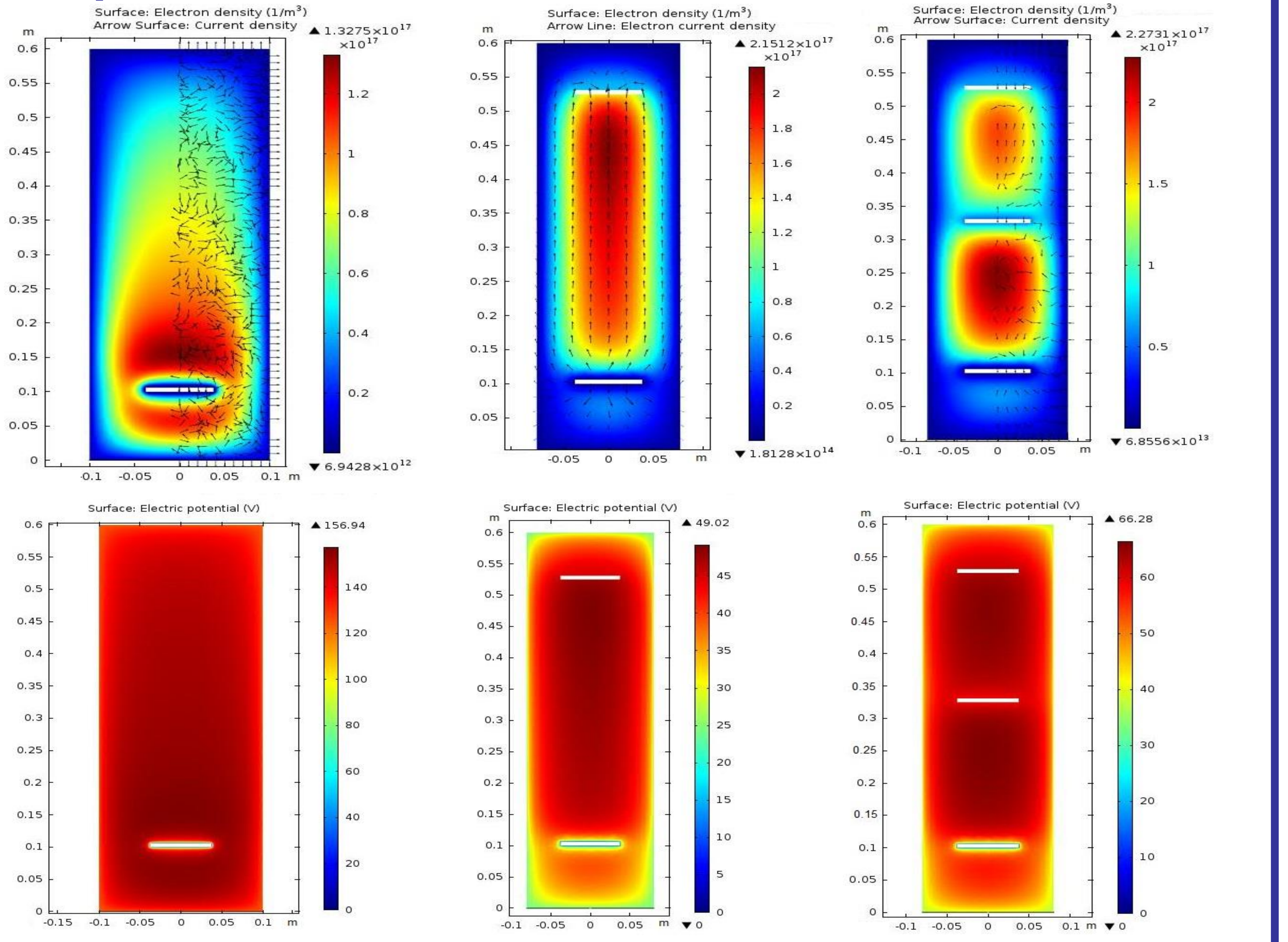




The low pressure cascade arc discharge was ignited in the large chamber 2 m long x 0.25m wide x 1m tall between vacuum arc cathode and remote anode (RA) positioned at 1.7m distance from the cathode, making the length of the remote arc column ~1.5m. The intermediate "mid" anode (MA) was also installed in the middle between the cathode and the remote anode. Three power supplies supported an arc discharge conducted between the cathode and the grounded chamber walls anode (WA), mid anode (MA) and remote anode (RA). The resistance both in the primary arc circuit and in the MA and RA circuits R1, R2 and R3 were ~0.5Ohm each. [4].

[4] S.Avtaeva, V.Gorokhovsky, S.Robertson, E.Shunko.,"Characterization of low-pressure arc plasma in large volumes," Journal of Physics: Conference Series (2018) (In Press).

Modeled electron density and plasma potential distribution across discharge tube



The values of the plasma potential Vp across discharge tube are close to the potentials of the RA and MA anodes, considerably exceeding the wall anode potential WA, while the RA potential is slightly greater than that of the MA. The electron temperature Te across the discharge tube does not exceed 5 eV, reaching greater values toward the cathode. Both Vp and Te are slightly increasing between 4 and 10 mtorr and decreasing with further increase of the pressure above 10 mTorr. In opposite, the electron density Ne shows decrease between 4 and 10 mTorr followed by steady increase above 10 mTorr resulting from the reduction of the plasma impedance. The plasma density and plasma potential distribution are affected by the intermediate anode, which is assisting the ignition and stabilizing the arc discharge in the long discharge tubes.

Modeled I-V characteristics and plasma parameters as a function of the pressure in low pressure cascade arc discharge with three anodes (RA, MA and WA) at thermionic current influx of 132A.