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Control of electron, ion and neutral heating in radio-frequency hollow cathodes[1]

JAMES DEDRICK, University of York

Low power and compact hollow cathode plasmas are of significant interest for applications including materials surface processing and electric propulsion. To control the charged and neutral particle dynamics under collisional conditions, radio frequency (rf) excitation can regulate power delivery to them via the sheath motion and formation of a dc self-bias voltage. In this study, we investigate electron, ion and neutral-gas heating in an rf hollow cathode flow reactor operating in argon at 1 Torr (133 Pa) with a fundamental applied-voltage frequency of 13.56 MHz. Two dimensional, fluid-kinetic simulations undertaken with the Hybrid Plasma Equipment Model corroborate measurements of the electron-impact excitation rate via phase-resolved optical emission spectroscopy for single frequency, dual frequency and tailored-waveform excitation. Structured ion energy distribution functions (IEDFs) are produced with a single voltage waveform as its frequency is increased at constant amplitude, and this is explained by a simultaneous increase in the Ar+ ion-neutral mean-free-path and decrease in the time-averaged extension of the sheath. Dual-frequency voltage waveforms are applied to regulate the ion-power fraction via the dc self-bias voltage, and thereby the temperature of the neutral gas as it travels between the plenum and expansion regions. Tailored voltage waveforms, generated through the superposition of multiple frequency components, induce temporal asymmetries in the electron heating. The resulting enhancement to the control of ion and neutral heating increases prospects for optimising particle energies and fluxes in intermediate-pressure, collisional plasma applications.

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