Magnetic Enhancement of the Electrical Asymmetry Effect in Capacitively Coupled Plasmas

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The development of real-time control strategies for key discharge parameters, such as densities, fluxes, and energy distributions, is of fundamental interest to many plasma sources. Over the last decade, multi-harmonic `tailored' voltage waveforms have been successfully employed to achieve enhanced control of key parameters in a wide range of radio-frequency (RF) plasma sources through application of the electrical asymmetry effect (EAE)[1]. More recently, the analogous magnetic asymmetry effect (MAE) has been numerically and experimentally demonstrated to achieve a notable degree of control in parallel plate RF plasma sources. The MAE is achieved via selectively magnetising the charged species adjacent to one electrode, altering the charge flux to the surface and enforcing a DC self-bias to maintain quasineutrality[2]. This study addresses the degree of control achieved by the MAE in a non-planar geometry via 2D fluid/kinetic simulations of a magnetised RF capacitively coupled plasma (RF-CCP) source[3] employing two different magnetic topologies. The simultaneous application of the EAE and MAE is then presented for the same geometry, demonstrating a degree of non-linear behaviour dependant upon the applied magnetic topology.

Control of the DC self-bias voltage η_{dc} is demonstrated for a single 600 Vpp, 13.56 MHz discharge in both 'convergent' (maximum on-axis field strength) and 'divergent' (minimum on-axis field strength) magnetic topologies. MAE induced modulations of η_{dc} = 0.13 Vpp and η_{dc} = 0.03 Vpp are achieved for each magnetic topology, respectively, for magnetic field strengths between 50 - 1000 G.

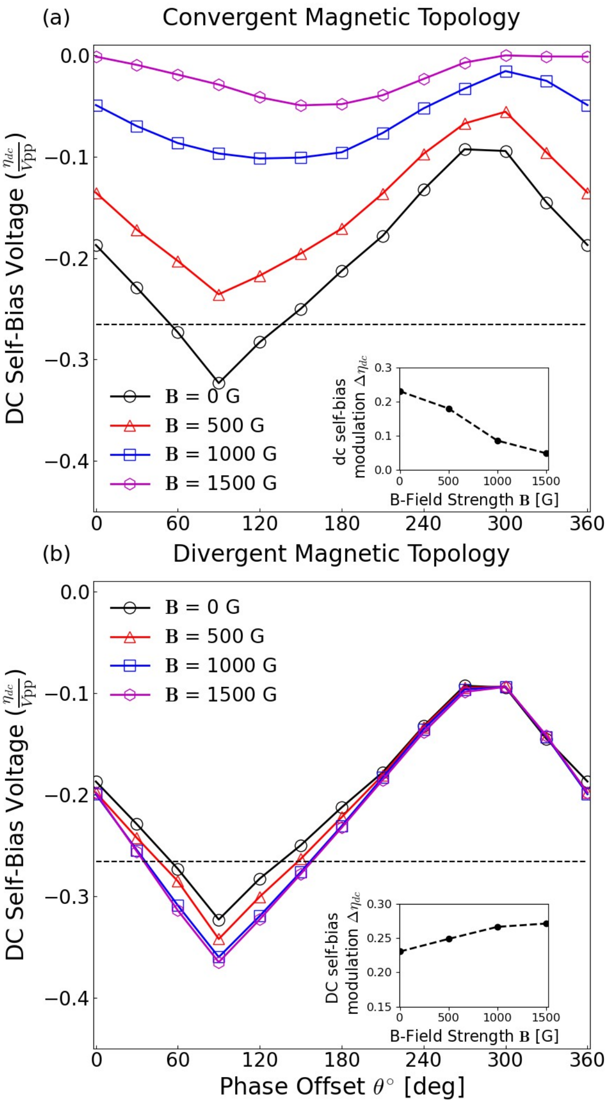

Fig. 1: Normalised DC self-bias voltages η_{dc}/V_{pp} , calculated via the RF phase-averaged alumina surface charge, at the alumina surface adjacent to the powered electrode for four 600 V_{pp}, 5 harmonic peak-type waveform discharges, with phase offsets in the range 0° < θ < 360° , employing (a) convergent and (b) divergent magnetic topologies. Inlay: DC self-bias modulation Δηdc , for each magnetic field strength.

Simultaneous application of an EAE and MAE is achieved through a multi-harmonic ‘peak’-type tailored voltage waveform employing varying harmonic phase offsets between $0^{o} < \theta < 360^{o}$. The degree to which the DC self-bias voltage is modulated by the applied EAE is mediated by the orientation and magnitude of the applied magnetic field. The EAE induced DC self-bias modulations exhibit non-linear behaviour in response to a superimposed MAE, such that the resulting DC self-bias differs from an additive combination of the two effects alone Simultaneous application of the electrical and magnetic asymmetry effects offers the possibility of further decoupling ion and electron dynamics in RF plasma sources, and represents an improvement over each approach in isolation.

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References:

[1] B. G. Heil, et. al., “On the possibility of making a geometrically symmetric RF-CCP discharge electrically asymmetric”, *Journal of Physics D: Applied Physics*, **41**, 165202, (2008).

[2] S. Yang, et. al., “Magnetical asymmetric effect in geometrically and electrically symmetric capacitively coupled plasma”, *Plasma Processes and Polymers*, **14**, 1–9, (2017).

[3] S. J. Doyle, et. al., “Decoupling ion energy and flux in intermediate pressure capacitively coupled plasmas via tailored voltage waveforms”, *Plasma Sources Science and Technology*, **29**, 124002, (2020).