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Experimental validation of sheath models at intermediate radio frequencies

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Sheaths in radio-frequency (rf) discharges play a dominant role in determining important properties such as the efficiency of power delivery and utilization, plasma spatial uniformity, and ion energy distributions (IEDs). To obtain high quality predictions for these properties requires sheath models that have been rigorously tested and validated. We have performed such tests in capacitively coupled and rf-biased inductively coupled discharges, for inert as well as reactive gases, over two or more orders of magnitude in frequency, voltage, and plasma density. We measured a complete set of model input and output parameters including rf current and voltage waveforms, rf plasma potential measured by a capacitive probe, electron temperature and ion saturation current measured by Langmuir probe and other techniques, and IEDs measured by mass spectrometers and gridded energy analyzers. Experiments concentrated on the complicated, intermediate-frequency regime of ion dynamics, where the ion transit time is comparable to the rf period and the ion current oscillates strongly during the rf cycle. The first models tested used several simplifying assumptions including fluid treatment of ions, neglect of electron inertia, and the oscillating step approximation for the electron profile. These models were nevertheless able to yield rather accurate predictions for current waveforms, sheath impedance, and the peak energies in IEDs. More recently, the oscillating step has been replaced by an exact solution of Poisson's equation. This results in a modest improvement in the agreement with measured electrical characteristics and IED peak amplitudes. The new model also eliminates the need for arbitrary or nonphysical boundary conditions that arises in step models, replacing them with boundary conditions that can be obtained directly from measurements or theories of the presheath.