A new approach to gas discharge theory with sheath boundaries

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The advent of personal computers revived interest in an old field of plasma physics, that of gas discharges. These partially ionized plasmas have evolved into low-pressure radiofrequency plasmas used for etching and deposition in semiconductor fabrication. In common use are ICPs (Inductively Coupled Plasmas), and CCPs (Capacitively Coupled Plasmas). A third type, helicon plasmas (HPs), require a DC magnetic field $B$ and are well understood but not yet accepted by industry. In cylindrical ICPs and HPs, plasmas uniform across the radius can be produced even when ionization is localized at the edge. This “anomalous skin depth” problem had been treated by electron migration to the center, but the pressure dependence of this mechanism does not agree with experiment.

To resolve the problem, we considered a cylinder of finite length bounded by endplates. The sheaths on the endplates can adjust themselves so that electrons can effectively cross $B$ by moving only axially. This “Simon short circuit effect” [1] allows electrons to follow the Boltzmann relation even across $B$. Assuming Maxwellian electrons and a simple ion fluid equation, we reduced the 1D problem to a simple equation for ion radial velocity $v$ which reaches the Bohm velocity at a radius which can be identified as the radial sheath edge at radius $a$. For uniform temperature $T_e$ and pressure $p$, the density profile follows a “universal” shape, always peaked on axis and independent of $p$ and $a$. Physically, this is because the profile changes only when there is a collision. The equation for $v(r)$ is an ordinary differential equation (ODE). A second ODE describes ionization balance at each $r$; a third treats neutral depletion. Our code EQM [2] solves these three equations simultaneously and is then coupled to the HELIC code [3] for HPs. Explanation and use of the short-circuit effect to treat finite-length discharges was essential.

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