Computational Studies of an Asymmetric rf Plasma using Particle-in-cell Techniques

by

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This thesis is entirely my own work,
except where specifically indicated.

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Abstract

A one-dimensional, electrostatic Particle-in-cell code in spherical geometry has been used to simulate low pressure, asymmetric, rf discharges. The simulation consists of two concentric, spherical electrodes, between which a plasma is generated. The inner electrode is connected to a voltage source through an external circuit, which can include a variable capacitor and resistor; the outer electrode is grounded. Electrons and ions are modelled explicitly by the simulation, and neutrals are included implicitly as a background gas pressure. Ion and electron motion is included and both species can make binary collisions with the neutrals. The simulation uses realistic ion masses and collision cross-sections for each species. Electrons make ionisation, excitation and elastic scattering collisions; while ions can undergo charge exchange and elastic scattering collisions.

The plasma is generated by operating the voltage source at a given voltage and frequency. An analytic model is derived for the sheath and bulk regions, based on a kinetic description of the plasma, in order to provide a comparison to the simulation. Results from the model are found to be in good agreement with those from the simulation for an atomic hydrogen discharge. The effects of changing the applied voltage and frequency, the background gas pressure and the radii of the electrodes on the steady-state parameters and structure of the plasma are examined and some scaling laws determined. The effect of changing the ratio of the electrode areas on the voltage distribution in the plasma is studied in detail and the dependence is found to disagree with predictions from other theoretical and numerical models. Heating of the electrons through interaction with the moving sheath edge has previously been determined to be the main mechanism sustaining low pressure, planar discharge models, and this effect is investigated for the asymmetric system. The relative distribution of power into ions and electrons is also determined. Ion energy and angular distributions at the electrodes are found to be dependent on both potential variation and ion collisions in the sheath.

A detailed Monte Carlo model of differential argon ion-neutral collision cross-sections was determined and used in the PIC code to simulate an argon discharge. Ion energy and angular distributions at the electrode, determined from the simulation, were found to be in good agreement with published experimental data.

Contents

Chapter 1

Low pressure rf plasmas

The advent of plasma physics, although with a long pre-history including Franklin's experiments with lightning, can probably be said to have begun in 1879 with Crooke's demonstration of the magnetic deflection of cathode rays, which he presciently described as "the fourth state of matter" (Penning (1957), Introduction). By the turn of the century much of the early parameterisation of plasmas had been accomplished by a group at Cavendish which included such luminaries as J.J Thompson, E. Rutherford and J.S Townsend. In the 1920s Langmuir published much of the early theory on the "discharge of arcs", and in 1929 Tonks and Langmuir coined the term plasma to describe the collective oscillation of electrons, although with the vagaries of fashion it did not come into common usage until about the 1950's. Much effort has concentrated on the development and understanding of hot, magnetically confined plasmas for fusion since the 1940s. However, it is not until about two decades ago that the technological application of low pressure rf plasmas for materials processing was realised.

Despite a long history many of the physical processes sustaining rf plasmas is poorly understood, particularly in the complex geometries used in technological applications today. Processing applications require precise control over the plasma, particularly as micro-structures become smaller and more complex. To continue advancing these technologies it is therefore essential to fully understand the physical processes driving the plasma rather than to rely on an empirical knowledge of the behavioural dependence on various input parameters. Plasmas involve complex interactions between charged and neutral particles, the self-fields of the charged particles and the applied fields as well as chemical and surface reactions. Measurements are difficult to make and the results are often difficult to interpret, particularly when complicated by hysteresis effects and unreproducability. Much of the effort in understanding the basic physical processes in plasmas has therefore been carried out in simplified systems, ignoring the complex geometry of industrial machines. Even so results have been contradictory and in a recent venture (Hargis *et al* (1994)) six similar GEC reference cells were manufactured and sent to several different labs in the USA, in order to determine the congruence of the results. Agreement between machines for