Physics of low pressure inductive discharges

V. A. Godyak, *Osram Sylvania, Beverly, MA 01915, USA*

Inductively Coupled Plasma (ICP) sources or rf discharges have been known for over a century. They have been used and studied in past decades mostly in two quite opposite regimes. At high gas pressure (about atmospheric pressure) ICP's produce plasma that is near equilibrium, while at low pressure (mTorr range) ICP's produce non-equilibrium plasmas. Low pressure ICP's have been used as ion sources for particle accelerators and as ion thrusters for space propulsion. Recently, interest in low pressure ICP's has been revitalized due to their great promise in plasma processing and lighting technology. The capability to provide a large plasma density at a low gas pressure and the absence of electrodes has made these discharges attractive in development of new technology and has stimulated intensive research activity on basic plasma phenomena occurring in such discharges.

Low pressure ICP typically operate at frequencies between hundreds of kHz and tens of MHz, in the gas pressure range between fractions of mTorr up to few Torr, at the discharge power from few W to few kW and are the simplest and the most effective way of plasma production in great variety of applications. In an ICP the main interaction between an electromagnetic field and the plasma, and thus rf power dissipation, takes place in the skin layer near the plasma boundary. Depending on plasma size, gas pressure and driving frequency, various interactions between the electromagnetic field and the plasma may occur. Under such conditions ICP's manifest a variety of plasma physics effects typical for hot fusion and space plasmas. Results of experimental and theoretical studies of ICP physics performed in the recent years will be given in the present lecture. Non-local coupling of the electron energy distribution function and its scalar integrals with the rf electric field (non-local electron kinetics) is well recognized as an underlying feature of low pressure rf discharges. Due to a large electron thermal conductivity, the electron energy relaxation length is larger than the plasma size and in absence of magnetic field the spatial distribution of plasma parameters is practically independent of the distribution of the rf heating field.

In the mTorr pressure range, when the characteristic scale of the electromagnetic field is smaller than an electron mean free path, non-local electrodynamics effects due to electron thermal motion may play an essential role in ICP operation. Under such conditions the rf current in the ICP is not locally coupled with the rf field (anomalous skin effect), resulting in a non-monotonic space distribution of rf field and rf current, collisionless electron heating and negative power absorption.

At a low driving frequency, requiring a relatively large rf magnetic field to induce a sustaining rf electric field, the rf Lorentz force acting on electrons in the ICP skin layer prevails over the rf electric force and electromagnetic field interaction with the plasma becomes non linear. Second harmonic potential in the skin layer, second harmonic current circulating around the main discharge current at the fundamental frequency and modification of the plasma density and ambipolar profile by ponderomotive force are typical in the non-linear regime.