§8. Measurement of Dynamic Properties of Pulse Modulated Induction Thermal Plasmas Using Langmuir Probes

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Inductively coupled thermal plasmas (ICTPs) has great advantages such as high gas temperature, high radical density and little impurity contamination. High pressure ICTPs have been used for various industrial applications at present material processing, melting, surface etching, deposition and so on. In these thermal plasma applications, it is very important to understand plasma properties, such as the plasma density (electron density, ion density and radical density), plasma temperature (electron temperature, ion temperature, and gas temperature), ow velocity and so on. These plasma parameters strongly affect reactivity in material processing mechanisms.

Recently we have begun to study the nitrification processes of titanium using a new type of ICTPs called Pulse-Modulated Induction Thermal Plasma (PMITP) [1]. The PMITP is a thermal plasma under periodical transient state generated by periodical amplitude modulation of a induction coil current. This dynamic plasma has possibilities to control the plasma temperature and radical density in time domain. However, the dynamic behavior of the plasma properties of PMITP has not been understood sufficiently. Even in conventional ICTPs we do not have enough study on the plasma properties, especially in high power and high pressure range. So, it is very important to measure electron density and temperature in high pressure and high power induction plasmas by Langmuir probes. In this work, we measured the electron density and temperature at a downstream region of a steady state ICTP by different probe methods (single, double, triple probe methods). After cross-checking of the results from different probe measurements, we carried out Langmuir probe measurement to study the dynamic change of the electron density and temperature when the rf coil current is periodically modulated.

The radial distribution of electron temperature and density at 200 mm below the coil end in steady-state ICTP measured by three different probe methods (single, double, triple probe methods). The results show both of the electron temperature and density agree well within a factor of 2 in the high-pressure induction plasmas. With increasing the gas pressure the electron temperature decreases due to the enhanced energy transfer to neutral particles through electron-neutral collisions and reduction of electron temperature brings a decrease of the electron density due to the enhanced recombination.

Figure 1 shows time response of the oating potential and ion saturation current measured by single probe(top), and the electron temperature and density measured by triple probe(bottom) at 200 mm below the coil end in Ar-PMITP with the input power modulation (SCL=100% and 60%). The electron density changes synchronously with the rf power modulation, but the electron temperature shows a different behavior from that of the electron density. The electron density shows a simple behavior corresponding to a rectangular change of the rf power. The delay of the density rise from the step increase of the rf power is considered to come from the plasma ow from upstream heating region to downstream. Rough estimation shows that the experimentally observed delay time is about 5 ms and the propagation time defined by the distance(200 mm) divided by plasma flow velocity(~30 m/s) is about 7 ms. So far the time response of the electron temperature is not understood clearly, but we consider this electron temperature change is related to the dynamic change of the plasma pro le in the induction heating region.

In pulse modulation experiments of high pressure ICTP, it is noticed that both the electron temperature and density 200 mm away from the main induction heating region change periodically in time signi cantly. Now the time response of the PMITP plasmas is continuously studied using both Langmuir probe and spectroscopic measurements.

Reference
[1]Y. Tanaka, T. Muroya, Y. Uesugi:in Proc. of ISPC-17, No. 86, 2005.

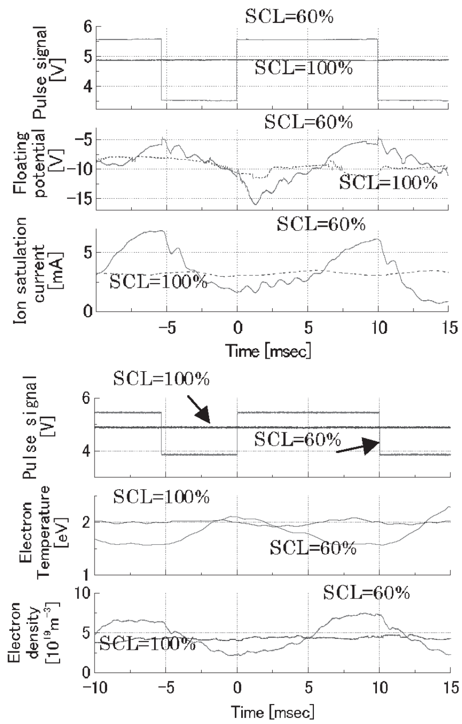

Fig. 1 Time response of the oating potential and ion saturation current(top) and the electron temperature and density(bottom) at r=0 mm and 200 mm down from the coil end when the rf coil current is rectangularly modulated. For comparison those in steady state condition are also shown in the gures.