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ION ENERGY AND PLASMA MEASUREMENTS IN THE NEAR FIELD OF AN ICRF ANTENNA*

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ABSTRACT

Plasma properties and ion energies have been measured in the near field of an ICRF antenna to determine the effects of rf fields in a magnetized plasma sheath on the energy of ions incident on the surface of the Faraday shield. A resonant loop antenna with a two-tier Faraday shield was used on the RF Test Facility at Oak Ridge National Laboratory (ORNL). The magnetic field near the antenna is ~2 kG, and the plasma density is $\sim 10^{11}$ cm^{-3} with an electron temperature of 6-10 eV. The time-varying floating potential was measured with a capacitively coupled probe, and the time-averaged electron temperature, electron density, and floating potential were measured with a Langmuir probe. Both probes were scanned poloidally in front of the antenna, parallel to the current strap. Diagnostics for measuring ion energies included a gridded energy analyzer located directly below the antenna. Measured ion energies are compared with predictions from a computational model for determining the energy and angular distribution of ions incident on a surface in a magnetized plasma sheath with a time-varying plasma potential.

INTRODUCTION

The interaction of the rf fields near an ICRF antenna with the surrounding plasma is important in understanding the generation of impurities from the antenna. Changes in the plasma parameters that result from the application of power from the antenna must be measured to help explain this interaction. Several of these plasma parameters have been measured within 1 cm of the surface of the Faraday shield tubes of a single-strap ICRF antenna in the RF Test Facility at ORNL. The antenna used in the experiment (shown in Fig. 1) was a resonant loop antenna operated at 42 MHz. The rf power was varied up to 60 kW, and the target plasma was generated by ~16 kW of 10.6-GHz ECH with a background hydrogen gas pressure of $(1\text{-}3) \times 10^{-4}$ Torr.

EXPERIMENT

The time-varying floating potential was measured with a capacitively coupled probe that was scanned in front of the antenna. The probe, described in Ref. 1, was calibrated at the rf frequency (42 MHz). A Langmuir probe scanning in the same area as the capacitive probe was used measuring the time-averaged electron temperature, electron density, and floating potential. The Langmuir probe was terminated on a small dc and rf load and thus measured the time-averaged current as

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a function of applied probe bias voltage. The ion saturation region of the measured probe characteristic appears to follow a $(V_{bias})^{1/2}$ dependence. With this dependence assumed, the time-averaged ion saturation current was calculated and subtracted from the measured current to give the time-averaged electron current. The electron temperature was then calculated from the lower portion of the Ie-V curve to avoid problems associated with response of a Langmuir probe in an rf plasma.[2] The electron density was calculated by measuring the ion current well into the saturation region and then corrected by using the LaFramboise method.[3] The time-averaged floating potential was taken from the time-averaged current measurement and then corrected for self-bias due to rf.[1,2]

A gridded energy analyzer located ~7 cm below the antenna measured the distribution of ion energies incident on a grounded surface in a magnetized rf plasma. Since the magnetic field was parallel to the surface and to the biasing grids of the analyzer, the analyzer was thin (≤1 mm thick) so that the ion energies perpendicular to the magnetic field could be measured.

RESULTS

The capacitive probe results indicate that the floating potential oscillates at the rf frequency and can reach values of up to 300 V p-p for an antenna current of ~400 A. The rf floating potential, normalized by the antenna current, is shown in Fig. 2 for various rf powers and gas pressures. The plasma loading and the plasma density were lower for the 0.1-m Torr case. While the precise scaling with the rf electric field has not yet been quantified, the potential generally increases with increased antenna current and plasma loading. The value of the potential is fairly constant in the poloidal direction, parallel to the current strap, and generally follows the magnetic field pattern of the antenna instead of the voltage distribution on the current strap. This result indicates that the potential formation is caused mainly by the electromagnetic fields and not by the electrostatic fields.

The electron temperature in front of the antenna increases with increased rf power. Without rf, the electron temperature is 6-10 eV. With rf, the electron temperature T_e increases to values above of 60 eV for an rf power of ~25 kW. It appears to be higher closer to the antenna surface. The electron density ~1 cm in front of the antenna is (3-6) × 10^{10} cm^{-3} and generally decreases when rf is applied. The density decreases closer to the antenna surface. The time-averaged floating potential at ~1 cm in front of the antenna increases from ~5 V without rf to over 70 V with ~25 kW of rf power.

The ion energy distribution measured with the energy analyzer shows an increase in the ion energies hitting a grounded surface during rf. Figure 3 shows the measured perpendicular ion energy distribution for rf powers of 0-25 kW. The energy distribution is peaked at 5-15 eV without rf and broadens to higher energies with increased rf power. Ion energies above of 300 eV have been measured with ~25 kW of rf power. This increase in ion energies will lead to increased erosion of the antenna surfaces. The net result of these measurements is that the electron temperature, plasma potential, and ion impact energies generally increase with rf power.

DISUSSION

This experiment was designed to test rf-plasma interactions near the antenna with rf fields and antenna conditions similar to those found in high-power rf experiments on confinement devices. The antenna voltages and currents in these experiments were 50-100% of those that would be expected in a tokamak. For example, at ~25 kW, the peak antenna voltage was ~20 kV and the antenna current was ~500 A. While most of the rf power in a tokamak will be absorbed in the resonance zone, the power and fields must pass through the low-density near-field area of the antenna. The amount of power deposited in the near field is not known exactly, but the power levels absorbed in our experiments are reasonably close to those expected. Some of this power appears to be coupling to the electrons and increasing their energy. This is consistent with theoretical predictions of electron heating in a rf sheath at the Faraday shield.[4,5] The electron temperature clearly increases with the rf electric field and rf power. Since the antenna used in this experiment has only one current strap, the effects of phasing between adjacent straps on the electric field structure, the plasma density, and the electron temperature near the antenna were not studied.

The increase in the ion energies measured with the energy analyzer is consistent with an increased sheath potential due to an increase in the electron temperature and in the fluctuating plasma potential. A computational model of a magnetized rf sheath currently in development,[6] shows that the energy of ions incident on a grounded surface will increase with increased electron temperature to values consistent with those measured with the energy analyzer. The model shows that the distribution is peaked near the time-averaged plasma potential. The time-averaged plasma potential is an input to the model and is taken to be the time--averaged floating potential plus $2.5T_e$ (Ref. 7).

CONCLUSIONS

Experiments have shown that large rf plasma potentials exist in front of the antenna. The potentials are caused by the rf power from the antenna and seem to follow the magnetic field pattern of the antenna. These large potentials cause an increase in the ion energies near the antenna surface and could increase the amount of erosion and impurity generation from the antenna. Although other mechanisms might exist for the observed increase in ion energies, this increase appears to be at least partially due to the increase in the sheath potential caused by the increase in the electron temperature.

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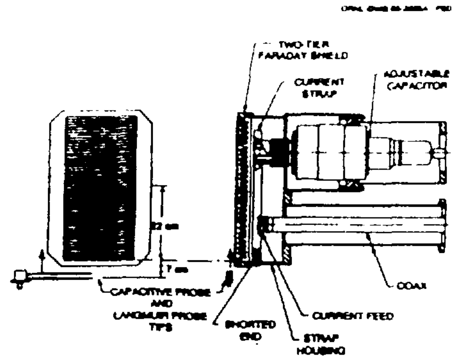

Fig.1 Front view and sectional view of the resonant loop antenna.

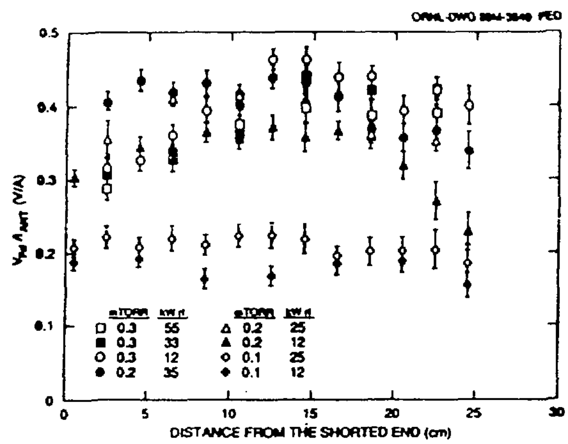

Fig.2 RF floating potential, normalized by the antenna current.

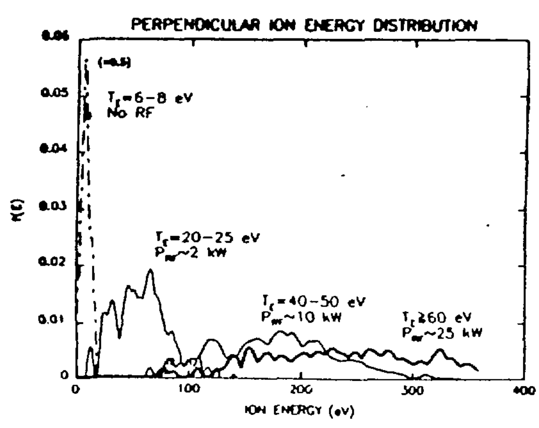

Fig.3 Measured perpendicular ion energy distribution for rf powers of 0–25 kW.

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