§13. Heat Load Due to Formation of RF Sheath at ICRF Antenna

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In the 5th experimental campaign on LHD, a corner of ICRF antenna was melted and small hole was made during ICRF heating experiment. The cause was assumed to be heat load due to RF sheath at ICRF antenna, and we estimate whether the heat load can pierce a hole in the ICRF antenna.

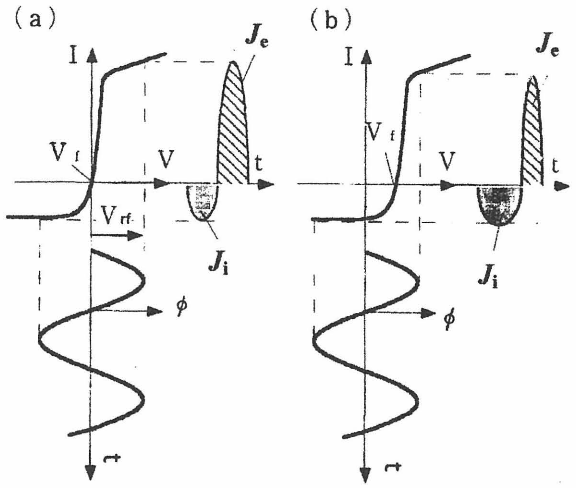

Fig. 1 Electron current and ion current in the case when (a) antenna voltage is oscillating around a floating potential (=0), (b) plasma potential increases, where time averaged electron current and ion current are same.

As shown in Fig. 1(a) when the voltage of antenna is oscillating around floating potential, there exists difference between electron current and ion current. However, plasma must be neutral. Therefore time averaged plasma voltage increases to V_0 as shown Fig. 1(b). This DC sheath voltage V_0 is estimated from ion and electron currents.

$$V_p = V_0 - V_{rf}\cos(\omega t)$$

$$J_i = -Zn_i eC_s,\quad J_e = \frac{n_e eC_e}{4}\exp\left(-\frac{eV_p}{T_e}\right)$$

$$C_s = \left\{\frac{k(T_i+T_e)}{m_i}\right\},\quad C_e = \left(\frac{8kT_e}{\pi m_e}\right)^{\frac{1}{2}}$$

where V_p is the difference between plasma and antenna voltages. J_i and J_e are ion and electron currents, respectively. With the condition, $\langle J\rangle = \langle J_i + J_e\rangle = 0$, the following relation is derived 1),

$$\frac{eV_0}{T_e} = \frac{1}{2}\ln\left(\frac{m_i}{4\pi m_e}\right) + \ln\left(I_0\left(\frac{eV_{rf}}{T_e}\right)\right)$$

When eV_{rf}/T_e is much larger than unity, V_0 is almost V_{rf}. Then time averaged heat load per unit area $\langle Q\rangle$ is $\langle Q\rangle \approx Zn_i eC_s V_{rf}$.

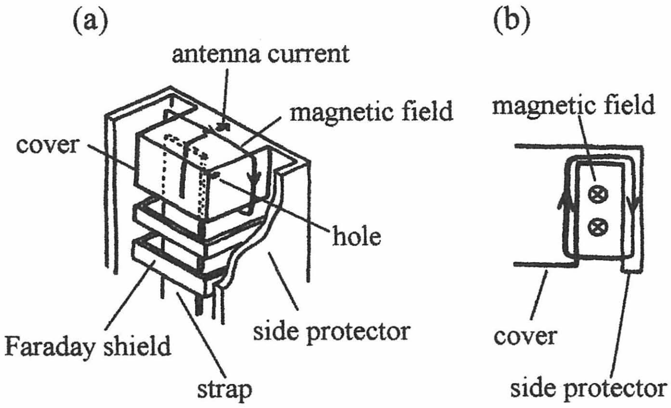

Fig. 2 (a) A schematic drawing of ICRF antenna. (b) A view from top of the antenna.

Antenna current induces magnetic flux between cover and carbon side protector as shown in Fig. 2(a) and the flux induces voltage along the circuit as shown in Fig. 2(b). Thus, potential of the cover oscillates with the voltage of V_{rf}. By Ampère law and law of electromagnetic induction, we estimated the RF voltage V_{rf} as 400V in the experimental condition *i.e.* loading resistance of 3Ω, input ICRF power of 400kW, and applied RF frequency of 38.47MHz. Then the heat load $\langle Q\rangle$ was estimated $1.4 MW/m^2$ by assuming the plasma parameter around ICRF antenna to be $T_e = T_i = 10 eV$ and $n_e = 1\times10^{18} m^{-3}$. The maximum pulse length during experiment was 7sec in the 5th experimental campaign. The temperature was estimated as 1600°C which was over the melting point, 1420°C. Therefore it is possible to make a hole in the ICRF antenna.

To prevent the ICRF antenna from melting we try a couple of measures in the 6th experimental campaign. One is putting stainless plate on the top of antenna not to make magnetic flux between cover and side protector, which induces RF voltage and make RF sheath. The other is changing the material of side protector from conductor (carbon) to insulator (boron-nitride, BN) not to make circuit as shown in Fig. 2(b).

Reference

1) Imai, T., et al., Journal of Nuclear Materials **266-269** (1999) 969-974.