03aD10P

高周波プラズマの等価回路モデル

Equivalent Circuit model of RF plasma with the transformer model

西田 健治朗，望月 慎太郎，安元 雅俊，太田 雅俊，J. Lettry,[1] S. Mattei,[1] 畑山 明聖
K. Nishida, S. Mochizuki, M. Yasumoto, M. Ohta, J. Lettry,[1] S. Mattei[1] and A. Hatayama

慶應義塾大学, CERN[1]
Keio University, CERN[1]

RF driven type H^- source is used as an injector of LINAC4. In the LINAC4 H^- source, the plasma is heated by a 100 kW, 2 MHz, 10% bandwidth RF system. It is required to match the load impedance Z_0 (see Fig. 1), which includes H^- source, to that of final amplifier R_M in order to maximize the power supplied to the plasma inside the source chamber. In spite of that, it is difficult to keep good matching condition since the impedance Z_0 changes widely due to plasma formation. In Ref. 1, the system frequency control has been proved to be useful for the matching problem. In this paper, we propose the analytic model of RF plasma as circuit elements aiming the prediction of the plasma impedance. This work allows us to calculate frequency characteristics of the circuit as well as its dependence on the plasma condition, which is to be investigated for improvement of the frequency control.

The source chamber that contains plasma is surrounded by RF coil. The geometric features of the system are as follows: radius of chamber $r_0 = 24\text{mm}$, the coil length $l = 28.5\text{mm}$, the number of turns of the coil $N = 5.5$. The plasma inside the chamber is described as a uniform medium whose permittivity ε_p is complex value:

$$\varepsilon_p = 1 - \frac{n_e e^2}{m_e \varepsilon_0} \frac{1}{\omega(\omega - i\nu_{en})}, \quad (1)$$

where n_e, ω and ν_{en} are the number density of electrons, the angular frequency of RF system and the collision frequency of electron, respectively (see Ref. 2 for more detailed explanation). The collision process with neutrals is assumed to be dominant for ν_{en}. since the neutral gas pressure for LINAC4 operation is relatively high (3 Pa). As seen in Fig. 1, the plasma is modeled as series circuit composed of resistance R_{plasma} and inductance L_{plasma}. On the basis of the transformer model[2], these are defined as follows:

$$R_{plasma} = \frac{2\pi N^2}{l\omega\varepsilon_0} \mathrm{Re}\left[\frac{ikr_0 J_1(kr_0)}{\varepsilon_p J_0(kr_0)}\right], \quad (2)$$

$$L_{plasma} = -\frac{\mu_0 \pi r_0^2 N^2}{l} \left| \frac{1}{J_0(kr_0)} - 1 \right|^2 - \frac{R_{plasma}}{\nu_{en}}. \quad (3)$$

where J_n and $k = k_0\sqrt{\varepsilon_p}$ are Bessel function of n-th order and the wave number of the plasma, respectively.

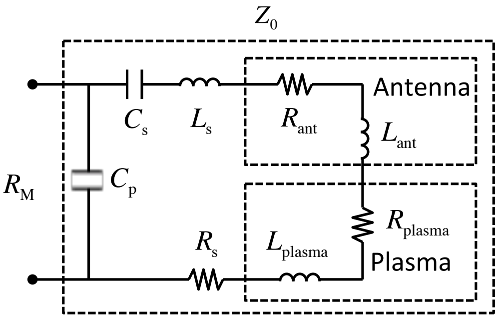

Fig. 1 Configuration of the matching circuit

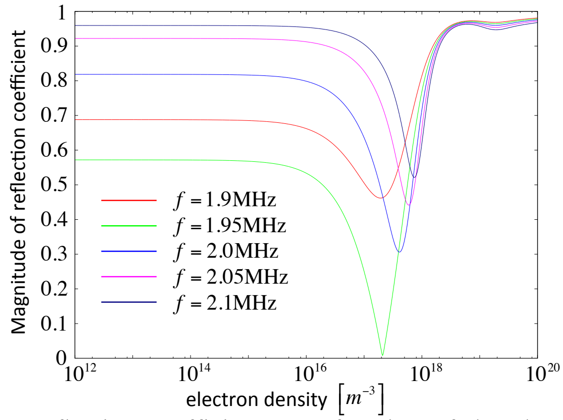

Fig. 2 Reflection coefficient as a function of the electron density for various frequencies.

The values of R_{plasma} and L_{plasma} can be given from Eqs. (1), (2) and (3) with two variables, i.e., frequency of the RF system f and electron density n_e. Note that the electron temperature, which determines the collision frequency ν_{en}, is assumed to be 10 eV. From the calculation results of R_{plasma} and L_{plasma}, voltage reflection coefficient Γ_V of the matching circuit has also been calculated whose definition is

$$\Gamma_V = \frac{R_M - Z_0}{R_M + Z_0}. \quad (4)$$

The value of each component of the matching circuit is provided in Ref 1. The calculation result of voltage reflection coefficient Γ_V has been shown in Fig. 2. The detailed comparison between the calculation results and experimental results will be provided in the poster session.

1. M.M. Paoluzzi, M. Haase, J. Marques Balula, D. Nisbet, AIP Conference Proceedings, **1390**, 265 (2011).
2. Pascal Chabert and Nicholas Braithwaite. *Physics of Radio-Frequency Plasmas.* Cambridge University Press, New york, 2011.