§10. Development of the Feedback Control System for Modulated Induction Thermal Plasma (FBC-MITP)

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Present report describes frequency dependence of the thermal plasma temperature control of a feedback control for modulated induction thermal plasmas(FBC-MITP). The FBC-MITP has been newly developed originally by the authors to give a direct controllability of thermal plasma temperature. In FBC-MITP, the thermal plasma temperature at the specified position can be controlled to follow an externally given periodical waveform. The FBC-MITP system is based on a concept of a pulse modulated induction thermal plasma (PMITP) system[1)] and an arbitrary-waveform modulated induction thermal plasma (AMITP) system[2)] that we have so far developed. The previous PMITP and AMITP are established by the modulated coil current, which provides periodical changes in the temperature and radical density after the modulated coil current waveform. On the other hand, the newly developed FBC-MITP directly controls its temperature at the observation region to follow an externally given waveform, for example, a rectangular or a triangular waveform. Figure 1 shows the block diagram of the FBC-MITP. This diagram is an example to use the PID controller as a control system $K(s)$. To control the temperature, we added spectrometric observation department and DSP to previous AMITP system.

For effective use of the FBC-MITP for material processing, it is necessary to understand its basic characteristics. The frequency dependence of the FBC-MITP system was investigated by adopting a sinusoidal waveform as a modulation signal, and then by changing the frequency of the sinusoidal waveform. Moreover, the temperature response against a step-changed control signal was also measured. The experimental condition for thermal plasma was as follows: the sheath gas is Ar with 40 slpm in gas flow rate, and the pressure in the chamber is at 30 torr, the time-averaged input power is about 11 kW, the observation position is at 10 mm below coil-end. The reference temperature signal was set to sinusoidal waveform with an amplitude of 2000 K and an off-set temperature of 7000 K. Figure 2 indicates the temperature time-variation under condition the reference frequency is

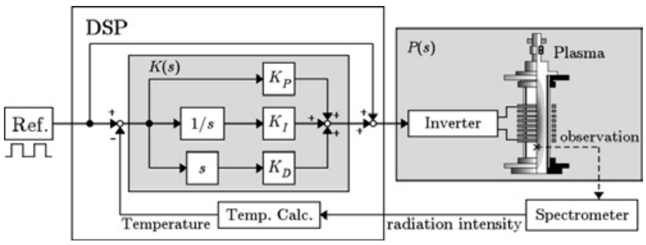

Fig. 1. Block diagram of feedback control for modulated induction thermal plasma (FBC-MITP).

3 Hz and 30 Hz in Ar AMITP and FBC-MITP. In case of 3 Hz in this figure, AMITP and FBC-MITP are following to the reference temperature. In case of 30 Hz, FBC-MITP is following to the reference temperature. On the other hand, AMITP is not following to the reference temperature. Moreover, amplitude is decrease. Figure 3 indicates the frequency dependence in temperature change in Ar AMITP and FBC-MITP. The gain in the vertical axis of Fig. 2 indicates the temperature amplitude as follows,

$$G = 10\log_{10}\left(T_{\mathrm{ex}}^{\mathrm{Ar\,p\text{-}p}} / T_{\mathrm{ref}}^{\mathrm{p\text{-}p}}\right). \quad (1)$$

In this figure, the temperature amplitude gain G is kept to be more than -3 dB high up to 100 Hz in the FBC-MITP, while the G for the previous AMITP without a feedback control drops down from 50 Hz. The temperature phase difference θ is kept to be more than -90 degree high up to 100 Hz while the θ for the previous AMITP without a feedback control drops down from 40 Hz.

As a result, the FBC-MITP can follow the thermal plasma temperature according to a given waveform up to about 100 Hz.

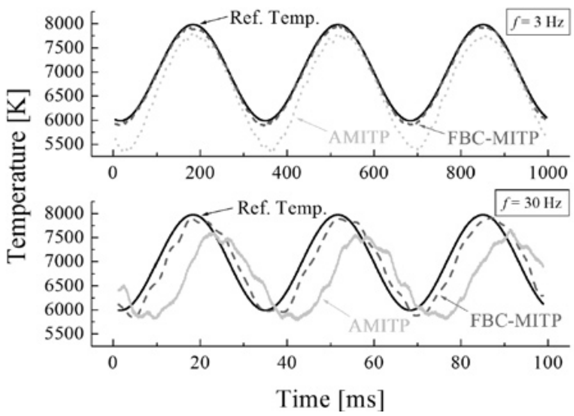

Fig. 2. Time-variation of the plasma temperature when the reference frequency is 3 Hz and 30 Hz.

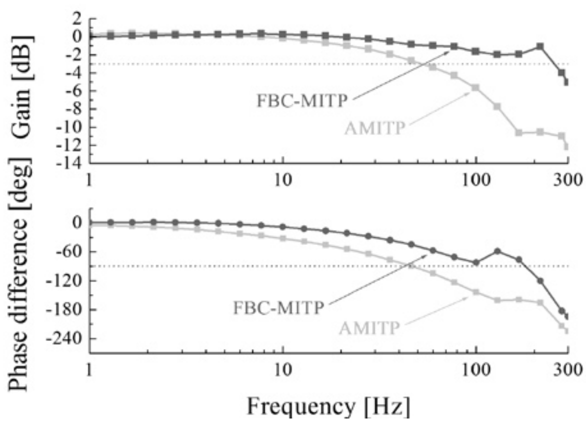

Fig. 3. Frequency dependence of temperature change in Ar AMITP and FBC-MITP.

1) Y. Tanaka, et al.: J. Phys. D, Appl. Phys., **41**, 18523 (2008)
2) Y. Tanaka, et al.: Appl. Phys. Lett., **90**, 071502 (2007)