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# Generation of Tandem Type of Modulated Induction Thermal Plasmas
# タンデム型変調誘導熱プラズマによる変動温度場の生成

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A tandem type of modulated induction thermal plasma (Tandem-MITP) system has been developed by using two RF power supplies to control temperature and reaction fields temporally and spatially in thermal plasmas. The present report describes the temperature variation of an Ar Tandem-MITP. Time variation of Ar excitation temperature was estimated by the two-line method. Results suggested that Ar excitation temperature in the thermal plasma could be controlled temporally and spatially by the Tandem-MITP system.

## 1. Intorduction

We have so far developed a pulse modulated induction thermal plasma (PMITP) system [1], an arbitrary-waveform modulated induction thermal plasma (AMITP) system [2] and a feedback control type of modulated induction thermal plasma (FBC-MITP) system [3] to control the temperature in the time domain. These systems can modulate the coil current amplitude to control the temperature in the time domain. For example, we have investigated the application of Ar-$O_2$ PMITP for $TiO_2$ nanoparticle. Those results implied that PMITP could control size and phase of $TiO_2$ nanoparticles synthesized [4]. We have also investigated the application of Ar-$N_2$ PMITP for surface nitridation of metallic specimen [5].

In this report, a tandem type of modulated induction thermal plasma (Tandem-MITP) system has been developed using RF power supplies and two coils for one plasma torch. This system was developed to control temperature and reaction fields temporally and spatially in thermal plasmas. We measured time variation in the Ar excitation temperature estimated by the two-line method. Results suggested that Ar excitation temperature in the thermal plasma could be controlled temporally and spatially by the Tandem-MITP system.

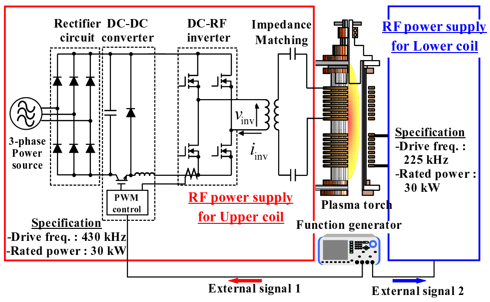


Fig. 1: Schematic of the tandem type of modulated induction thermal plasma (Tandem-MITP) system.

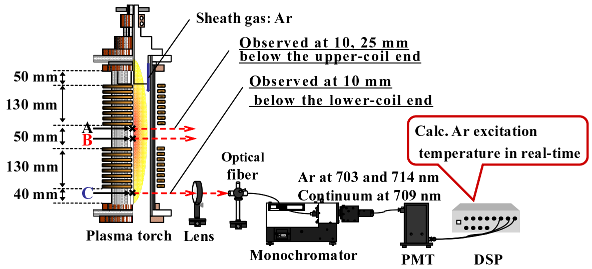


Fig. 2: Plasma torch and spectroscopic observation system.

## 2. Experimental setup

### 2.1. Experimental conditions

Fig. 1 shows a schematic of the Tandem-MITP system, and Fig. 2 portrays the plasma torch and spectroscopic observation system. The torch is composed of two coaxial quartz tubes with 430 mm length. The inner tube has an inside diameter of 70 mm. The plasma torch wall is cooled by the flowing water. For establishing Tandem-MITP, we used Ar as a sheath gas. The gas flow rate is 40 slpm for axial gas and 40 slpm for swirl gas. The pressure in the chamber is fixed at 70 torr. This torch has two eight-turn induction coils. Distance between upper-coil-end and lower-coil-top is 50 mm. Two-coils are connected with a RF power supplies, respectively. The driving frequency for the upper coil $f_1$ was fixed at 430 kHz due to the power supply rating. The driving frequency for the lower coil $f_2$ was 225 kHz, i.e almost a half of $f_1$. This $f_2$ was determined to avoid a mutual resonance between the upper and lower coil circuits, and to obtain high input power to the plasma because the input power is generally proportional to square of frequency.

### 2.2. Spectroscopic observation system

Spectroscopic observation was carried out at 10, 25 mm below the upper-coil end and at 10 mm below the lower-coil end, which are designated by A, B and C in Fig. 2. We measured temporal variations in the radi-

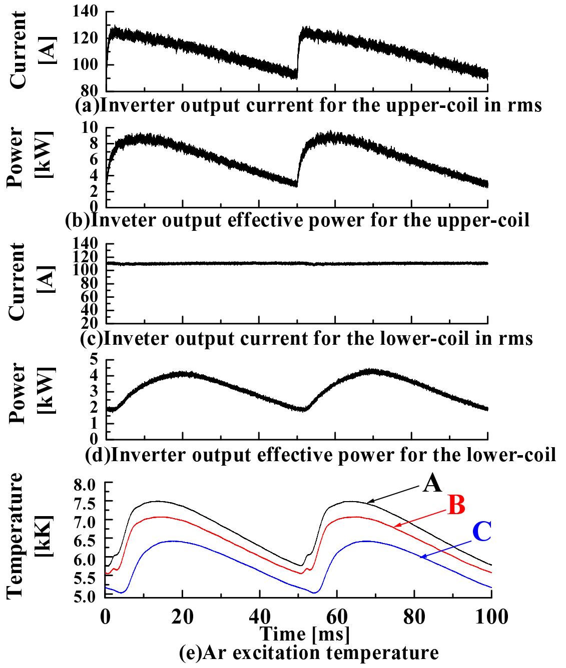


Fig. 3: Time evolution in (a)inverter output current for the upper-coil in rms, (b)inverter output effective power for the upper-coil, (c)inverter output current for the lower-coil in rms, (d)inverter output effective for the lower-coil, (e)Ar excitation temperature. The upper-coil current amplitude is modulated into a sawtooth waveform and the lower-coil current amplitude is non-modulated.

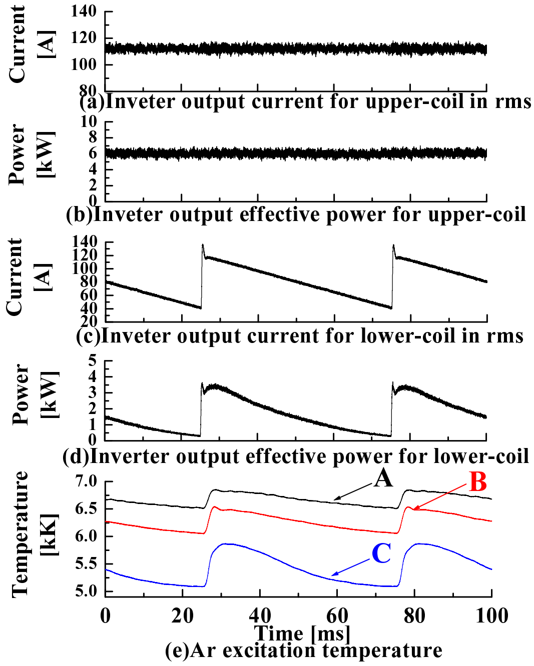


Fig. 4: Time evolution in (a)inverter output current for the upper-coil in rms, (b)inverter output effective power for the upper-coil, (c)inverter output current for the lower-coil in rms, (d)inverter output effective for the lower-coil, (e)Ar excitation temperature. The upper-coil current amplitude is non-modulated and the lower-coil current amplitude is modulated into a sawtooth waveform.

ation intensities at 703 and 714 nm for Ar lines and 709 nm for continuum. Use of the radiation intensities of these spectral lines yields the Ar excitation temperature between the specified levels by the two-line method. This calculation was done in real-time in Digital Signal Processor(DSP).

## 3. Exprimental results

Fig. 3 shows time evolution in (a)inverter output current for the upper-coil in rms as shown in Fig. 1, (b)effective power for the upper-coil, (c)inverter output current for the lower-coil in rms, (d) effective power for the lower-coil, (e)Ar excitation temperature. These results were obtained for the non-modulated current of the lower-coil and the modulated current of the upper-coil. Similarly, Fig. 4 indicates those for the non-modulated current of the upper-coil and the modulated current of the lower-coil. The current modulation was conducted in a sawtooth waveform.

As illustrated in Figs. 3(a) and 3(b), the effective power of the upper-coil changes according to the upper-coil current. On the other hand, the effective power for the lower-coil changes between 1.9 kW and 4 kW regardless of non-modulated current of the lower-coil as shown in Fig. 3(a). This is because of high-temperature thermal plasma flowing into the lower-coil, which causes higher joule heating in the lower-coil region. Thus, the Ar excitation temperature at any position changes with an amplitude of 1500 K according to the upper-coil current, as seen in Fig. 3(e). Whereas, Figs. 4(a) and 4(b) indicate that the effective power of the upper-coil keeps constant of 6 kW according to the upper-coil current. In this case, only the effective power for the lower-coil rises rapidly just after a jump-up in the lower-coil current. In Fig. 4(e), the Ar excitation temperature at C increases rapidly from 5000 K to 5800 K immediately after an increase in the lower-coil current. The temperature-changes at A and B are smaller than that at C. The above results implied that a Tandem-MITP can control the Ar excitation temperature temporally and spatially in thermal plasmas.

## 4. Conclusion

In this report, we measured time variation of Ar excitation temperature estimated by the two-line method using Ar atomic lines. Results suggested that Ar excitation temperature in the thermal plasma could be controlled temporally and spatially by the Tandem-MITP system.

### References

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