INFLUENCE OF VARIOUS GAS INCLUSIONS UPON RESPONSE OF PULSE MODULATED THERMAL PLASMA

Tadahiro Sakuta, Masayuki Katayama and Yasunori Tanaka

Department of Electrical and Electronic Engineering, Kanazawa University, 2-40-20 Kodatsuno, Kanazawa 920-8667, JAPAN

Abstract

The influence of various gas inclusions such as H₂, O₂, N₂ and CO₂ upon a pulse modulated Ar induction thermal plasma at atmospheric pressure were investigated. It was found that molecular gas inclusion causes a lower response time of the thermal plasma at a instance of pulsation and a lower minimum temperature in a pulse modulation cycle.

2. Introduction

The thermal plasma under the atmospheric pressure has widely been used for many technologies such as the production of new materials, material processing and destruction of the wastes and the plasma spraying because of its high reaction activity and high temperature. Recently, the inductively coupled thermal plasma is being paid much attention in many industrial fields, since the inductively coupled plasma (ICP) is free from any contamination such as electrode vapors [1-3].

For the purpose of using ICP in the materials processing fields, much effort has been until now made to sustain the ICP statically under the steady condition. On the other hand, we have developed a new system for sustaining ICP with a function of periodical amplitude modulation of the coil current by using MOSFET inverter power supply. We call the thermal plasma sustained by this system as “pulse modulated induction thermal plasma (PMITP)”.

The intentional modulation of the coil current may induce the ICP to be under the transient and dynamic state as well as chemically non-equilibrium condition. This has a potential of introducing a novel technology for new materials processing. In addition, the use of this PMITP allowed us to investigate the inherent transient properties of a given gaseous plasmas free from any contamination fundamentally.

In order to use the PMITP for the material processings, it is very important to know the dynamic change of the internal state of the PMITP and its bulk response time. Then in the present paper, the dynamic response times of the Ar based PMITP was investigated with spectroscopic method using radiation intensity of Ar spectral line. The influence of various gas injections such as N₂, O₂, H₂ and CO₂ upon the response times of the PMITP was also investigated. Furthermore, for the various gas PMITP, the effect of shimmer current level (SCL), which is the ratio of lower to higher level of the coil current, on the response time of the plasma was also discussed.
2. Experimental
2.1 Plasma torch and power supply

Figure 1 illustrates a schematic diagram of the plasma torch used in the experiment. The torch was composed of two coaxial quartz tubes with a 345 mm length. The inner tube has an inside diameter of 70 mm. Between the inner and the outer tubes, cooling water flowed from downer to upper side with a swirl to keep the wall temperature around 300 K. Argon-additional gas mixture was supplied as a sheath gas along the inner tube wall with a swirl to prevent the plasma from contacting to damage the inner tube. The plasma in the tube receives a power from an 8-turns coil by the electromagnetic coupling. The electric current flowing in the coil has a frequency of 450 kHz. The power supply has a MOSFET inverter power supply rated of 50 kW. This has a function of the amplitude modulation of the coil current. The main control functions are the 1) change of the Simmer Current Level(SCL) which is the ratio of lower current level to higher current level, 2) change of duty factor which is a ratio of on-time duration to the total pulse period.

![Fig.1 Plasma torch.](image-url)
2.2 Spectroscopic observation system

Figure 2 shows the spectroscopic observation system. The observation was carried out on the center axis at 10 mm under the coil end. The light radiated from the observation position was transmitted through a camera lens and an optical fiber bundle to the slit of a monochromator. At the focal plane of the monochromator, three optical fiber bundles were installed to measure the radiation intensity at three different wavelengths. At each of another ends of the fiber bundles, photomultipliers were set to convert optical signals to electrical ones. The wavelength width observed by this system is 1.0 nm for each of detecting channels. In this experiment, we measured Ar atomic spectral lines at the two specified wavelengths, and continuum radiation at one wavelength free from overlapping any spectral line as background radiation. We chose two couples of lines 751 and 764 nm, and 703 and 714 nm for Ar atomic lines, and neighbor wavelengths for continuum.

2.3 Parameter definition and experimental condition

The system has a function of amplitude modulation of the coil current. We have controllable parameters such as “HCL” which is the higher current level, “LCL” the lower current level, “on-time” the time period with the higher current level and “off-time” the time period with the lower current level. We also define the ratio LCL/HCL as SCL shimmer current level. By controlling these parameters, the following feasibilities and effects are expected: (i) control of the average power in time domain, (ii) extremely high or low electromagnetic field operation, (iii) introduction of thermally and/or chemically non-equilibrium effects. In this paper, we fixed “on-time” and “off-time” to 10 ms and 5 ms, respectively. The HCL was set to the value corresponding to a input power 30 kW for each plasma. Pressure inside the torch was fixed to 0.1MPa by an automatic pressure control unit.
3 Results and discussions

3.1 Coil current waveforms and time variation in radiation intensity of Ar line

Figure 3 shows the modulated coil current waveforms in Ar, Ar-N₂ and Ar-CO₂ PMITP for examples. The LCL or SCL is taken as a parameter with HCL fixed. The amplitude of the coil current for these three kinds of gas plasma can be modulated into an almost squire waveform corresponding directly to the pulsing signal. This tendency can be found for Ar-H₂ and Ar-O₂ plasmas. The stepped change time of the coil current for any gas plasma is around 80 µs which is much shorter than thermal plasma inertia as described later. Therefore, we can investigate the inherent response time of the thermal plasma versus coil change.

Figure 4 indicates the time variation in the radiation intensity of Ar spectral line at a wavelength of 751 nm for Ar, Ar-N₂ and Ar-CO₂ PMITP. The spectral intensity for any SCL and any gas kinds here changed periodically with AM modulation of coil current, however, their waveforms are considerably far from the squire shape. This change results mainly from the response time of the thermal plasma. The similar waveforms can also seen for other Ar atomic lines in further experiments. For the purpose of summarizing the response time of the thermal plasma, the characteristic times including rising time and on-delay time were defined as indicated in Fig.5. Figure 6 shows the rising time and the on-delay time for five gas plasmas. These characteristic times increased by decreasing SCL. This is attributed to the fact that at just before the on-operation, the plasma has a minimum temperature during a modulation cycle. Another important point is that the on-delay time increases by molecular gas inclusion.
compared with pure Ar plasma. Especially, CO\textsubscript{2} inclusion causes drastic increase in the on-delay time. This is because CO\textsubscript{2} reduces the temperature just before the on-operation remarkably as described later.

3.2 Time variations in Ar excitation temperature

We measured the Ar excitation temperature by the two-line method using the lines at 703 nm and 714 nm to confirm the temperature change. Figure 7 demonstrates the temperature variation in Ar, Ar-H\textsubscript{2}, Ar-N\textsubscript{2}, Ar-CO\textsubscript{2} and Ar-O\textsubscript{2} plasmas measured at 10 mm below the coil end. The temperature in pure Ar plasma hardly changed with the coil current, while it in N\textsubscript{2} and CO\textsubscript{2} plasma periodically varies with coil current. Figure 8 shows the maximum and minimum temperature in a modulation cycle versus SCL. The maximum temperature has almost similar magnitude of 18000 K irrespective of SCL. However, the minimum temperature decreases with SCL. This means that we can control the minimum temperature by setting SCL with keeping the maximum temperature.

4 Conclusion

The response times of the pulse modulated thermal plasma were measured for Ar, Ar-H\textsubscript{2}, Ar-N\textsubscript{2}, Ar-CO\textsubscript{2} and Ar-O\textsubscript{2} gas. The Ar excitation temperature was also estimated by the two-line method. It was found that molecular gas inclusion delayed the response of the plasma at a instance of pulse change of the coil current and that it decreased the minimum temperature of the plasma in a modulation cycle. Furthermore, we confirmed that the minimum temperature in a modulation cycle could be controlled by changing SCL.

5 Acknowledgement

The present work was supported partially by a Grant-in Aid for Scientific Research (B)(1)(No.11555078) in 1999-2001.
References

Fig. 7 Temperature variation in different gas plasmas.

Fig. 8 Dependence of maximum and minimum temperature in a modulation cycle.