High-Speed Two-Directional Analysis of Temperature Characteristics in Multiphase AC Arc

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Abstract: Fluctuated temperature field of a multiphase AC arc were successfully visualized by a high-speed camera. The effect of driving frequency on spatial characteristics of high temperature region was elucidated by observing arc from two directions. The arc concentrates in the center of the reactor as the driving frequency increases. High temperature region suitable for the evaporation process can be maintained at the higher frequency than 120Hz. These understandings of fundamentals in the multiphase AC arc enable practical application.

Keywords: thermal plasmas, high-speed visualization, temperature measurement

1. Introduction

Thermal plasmas have been applied in various industrial fields due to its unique advantages such as high enthalpy, high chemical reactivity, and oxidation or reduction atmospheres in accordance with required chemical reactions. These advantages enable to advance in plasma chemistry and plasma processing [1].

A multiphase AC arc is one of the most attractive thermal plasmas among various thermal plasma reactors because it has many advantages such as large plasma volume, energy efficiency, and low gas velocity. Therefore, the multiphase AC arc has been applied to a massive powder processing such as in-flight glass melting [2] and nanomaterial fabrication process [3]. Understanding the temperature characteristics is significantly necessary to apply the multiphase AC arc to the material synthesis efficiently.

Recently, the imaging technique based on high-speed camera observation with band-pass filters has been developed. Steady-state or axisymmetric arc temperature distribution was successfully visualized [4]. However, temperature fields and its fluctuation characteristics in the multiphase AC arc have not been understood yet because of the difficulties of fluctuated temperature in the multiphase AC arc.

The purpose of this study is to clarify the spatial characteristics of arc fluctuation phenomena and temperature characteristics of multiphase AC arc. The effect of the frequency and arc current on the arc fluctuation phenomena and the temperature characteristics was discussed because AC applied condition and arc current are essential parameters to control the plasma field.

2. Experiments

The schematic diagram of the multiphase AC arc shown in **Fig. 1**. It consists of 6 electrodes, arc chamber, vacuum pump, and AC power supply at 60Hz. These electrodes with a diameter of 6 mm were made of tungsten (98%) and cerium oxide (2%). The arc chamber was filled with argon gas. The electrodes are at an angle of 45 degree with regard to the horizontal plane. The ambient pressure was set at 100 kPa. Arc current for each electrode was fixed at 120A. The distance between the opposing electrodes was 52 mm. Argon gas was injected around each electrode at 5 L/min. The frequency was changed from 60Hz to 180Hz. Two high-speed cameras were set on top and side of the chamber for synchronized analysis of temperature characteristics.

An optical system including the band-pass filters was combined with the high-speed camera as shown in **Fig. 2**. Emission from thermal plasma consists of line spectra due to ionic species and/or bound-bound transition of atomic, and the continuous spectra due to free-to-free or free-to-bound transition. The temperature was calculated accurately in consideration with argon line with continuous spectra.

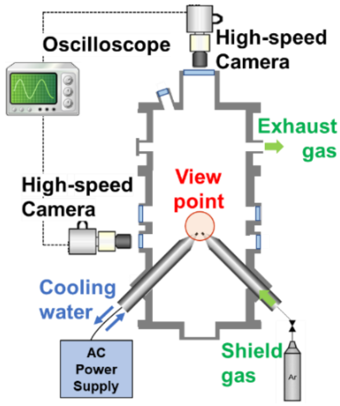

Fig. 1 Schematic image of multiphase AC arc generator.

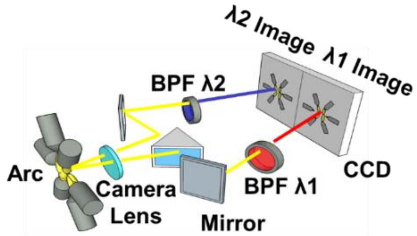

Fig. 2 Conceptual diagram of measurement system.

3. Results and Discussion

Figure 3(a) shows the results of the emission spectroscopy analysis during plasma generation. The observation position is 40 mm above the electrodes. The bandpass filters of 675 ± 5 nm and 795 ± 5 nm were selected to transmit the line spectrum of argon at 675.2834 nm and 794.8176 nm. **Figure 3(b)** is a theoretical curve used for temperature calculation, showing the relationship between the relative intensity and temperature.

Figure 4 shows temperature distributions measured from two directions during one AC cycle of 60Hz. The position of the electrodes was captured by edge detection [5] and indicated by white line. The obtained temperature distributions indicated that the temperature of the multiphase AC arc was fluctuated in the range of 6,000 K to 17,000 K. The temperature was highest near the electrodes and decreased as the distance from electrodes increased. From the top, the arc between the two electrodes appeared to be liner, while from the side, the arc between two electrodes appeared to form a mountain-like arc downstream.

Figure 5 shows temperature distributions measured from two directions during one AC cycle of 180Hz. Arc fluctuations are suppressed and the then plasma region is concentrated in the center of the reactor in two directions. This is due to the suppression of arc fluctuations with increasing frequency [6].

Figure 6 shows arc existence probability measured from two directions of 60, 120, and 180Hz to understand the spatial characteristics. Arc fluctuation was suppressed as driving frequency increases. With an increase the frequency, interval of arc discharge becomes shorter, and the arc is concentrated at the center region. The arc temperature at the center is increased and the arc fluctuation is decreased. A high temperature region which stably exists near the center at a high frequency is suitable for synthesis of functional nanomaterials.

4. Conclusion

Arc fluctuation phenomena and temperature fields of multiphase AC arc were successfully visualized by high-speed camera and band-pass filters. In addition, the spatial characteristics of high temperature region can be elucidated by observing arc from two directions. Arc temperature of multiphase AC arc was fluctuated from 6,000 K to 17,000 K. This shows that the refractory metals or ceramics can be completely treated in the multiphase AC arc. Understanding the arc fluctuation phenomena and temperature characteristics in the multiphase AC arc enables us to apply this to the various material processing at high productivity compared to the other thermal plasmas.

5. References

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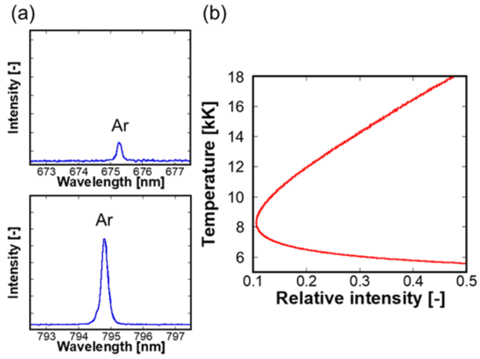

Fig. 3 (a) Emission spectra of the multiphase AC arc measured for the center wavelength of 675 nm and 795 nm and (b) The relationship between the arc temperature and relative intensity.

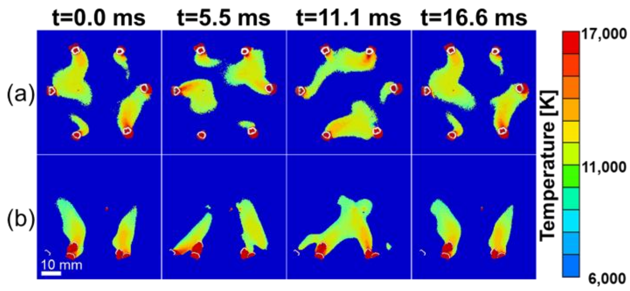

Fig. 4 Temperature distributions measured (a) from the top and (b) from the side during one AC cycle of 60Hz.

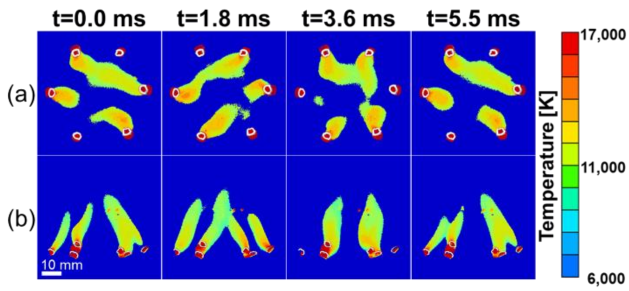

Fig. 5 Temperature distributions measured (a) from the top and (b) from the side during one AC cycle of 180Hz.

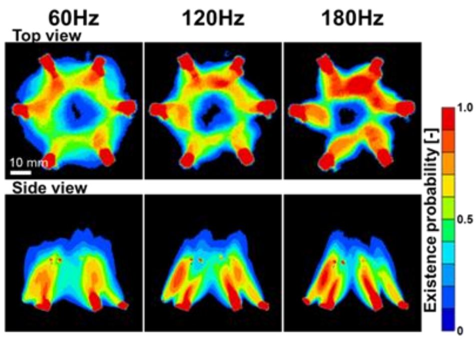

Fig. 6 Effect of the frequency on arc existence probability measured (a) from the top and (b) from the side.