S7-3

多相交流アークの変動現象とナノ粒子合成への応用
Fluctuation Phenomena in Multiphase AC Arc for Nanoparticle Synthesis

田中学[1]，釘宮悠太[1]，末永拓也[1]，玉江藍花[1]，渡辺隆行[1]，
松浦次雄[2]，上田紹夫[3]，東崎英樹[4]
Manabu TANAKA[1], Yuta KUGIMIYA[1], Takuya SUENAGA[1], Aika TAMAE[1],
Takayuki WATANABE[1], Tsugio MATSUURA[2], Tsuguo UEDA[3], and Hideki TOUSAKI[4]

九大工[1]，タソーアーク株式会社[2]，福伸工業株式会社[3]，タマダ株式会社[4]
Kyushu Univ.[1], Taso Arc Co.[2], Fukushin Kogyo Co., Ltd. [3], Tamada Corp. [4]

1 Introduction

A multiphase AC arc (MPA) is one of the most attractive thermal plasmas due to its advantages such as higher energy efficiency compared with conventional thermal plasmas. However, a few issues remain to be solved for utilization in industrial fields. In spite of intensive experimental works, electrode erosion is one of the most important issues because it determines electrode lifetime and purity of the products.

Erosion mechanism in MPA has been investigated based on high-speed visualization [1]. Erosion due to ejection of droplet larger than 100 μm in diameter is dominant at cathodic period, while evaporation is dominant at anodic period. The droplet ejection at cathodic period is caused by electrode melting due to anodic heat transfer.

Required properties for cathode and anode are different. Low work function and high melting point are important cathode properties for stable electron emission. In contrast, high thermal conductive material is suitable for anode as electron recipient. However, there is a lack of appropriate electrode material which satisfies required properties at both cathodic and anodic periods, resulting in sever erosion in conventional single-phase [2] or multiphase [1] AC arcs.

An innovative diode-rectified MPA (DRMPA) has been successfully developed to overcome afore-mentioned situation [3]. However, the understanding of the fundamental phenomena in the DRMPA is insufficient to utilize it in application fields. The purpose of the present study is to investigate the fluctuation phenomena. Another purpose of the present study is to investigate the feasibility of this plasma source in material processing.

2 Experimental

Twelve diodes are placed between the electrodes and transformers. Thus, the electrodes were divided into pairs of cathode and anode, namely bipolar electrodes. Representative waveform of arc current is presented in **Fig. 1**. **Figure 2** shows the schematics of the experimental setup with electrode configuration. Each electrode consists of cathode made of water-cooled 2wt%-La_2O_3 W rod with 6.0 mm in diameter and anode made of water-cooled Cu. Twelve pairs of electrodes are symmetrically arranged at angle of 30 deg. DRMPA was generated among 12 bipolar electrodes in the chamber which was filled by Ar at atmospheric pressure. Arc current was changed from 120 to 250 A.

Fluctuation phenomena were visualized by a high-speed camera with band-pass filters at 795 nm and 675 nm as shown in **Fig. 3**. Emission coefficients at different wavelength ranges were estimated considering atomic and ionic line emission as well as continuum emissions. Arc temperature was calculated based on the intensity ratio of two different wavelengths. Typical framerate was 1×10^4fps with shutter speed of 50-100 μs. Electrode erosion rate was measured by weight decrease after arcing for 15 min.

Nanoparticle syntheses by the MPA and DRMPA were also carried out. Silicon powder with 5 μm in diameter was injected into high temperature plasma from the top of the chamber. Feed rate of Si raw material was controlled at 5-50 mg/min. Flow rate of Ar carrier gas was changed from 5 to 30 L/min. Synthesized nanoparticles were observed by scanning electron micrograph (SEM).

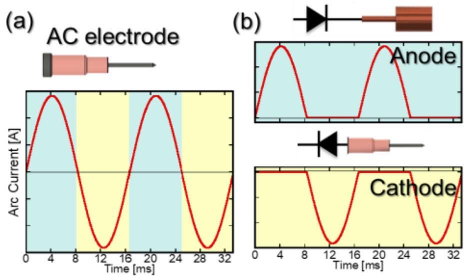

Fig. 1 Representative waveform of arc current for (a) MPA and (b) DRMPA.

3 Results and Discussion

Figure 4 shows the visualized temperature distribution of the DRMPA at different arc currents. Arc near the cathode is constricted and corresponding temperature is higher than 16,000 K. In contrast, arc temperature near the anode was about 13,000 K. This difference can be explained by the different current density near the arc. Arc temperature at center of the furnace is fluctuated in the range from 6,000 to 11,000 K. Higher temperature region than 6.000 K was obviously became larger with an increase of arc current. As a conclusion, the arc temperature in the DRMPA is sufficiently high to melt and/or evaporate the raw material in powder processing.

Figure 5 presents representative SEM image of the produced Si nanoparticles. Obtained results indicated that the most of the nanoparticles have the diameter in the range from 100 to 500 nm, which range is one order larger than the nanoparticles by conventional thermal plasmas [4]. This can be briefly explained by the higher vapor concentration in the multiphase arc due to larger feed rate of the raw powders.

4 Conclusion

Fluctuation phenomena in the diode-rectified multiphase AC arc under atmospheric pressure has been successfully revealed by high-speed camera system with appropriate band-pass filters. Emission coefficients at different wavelength ranges including line and continuum contributions were estimated. Arc temperature was then calculated based on the intensity ratio method. Synthesized particles have significantly larger diameter compared with that produced by the conventional thermal plasmas. Obtained remarks suggest the diode-rectified multiphase AC arc is a promising plasma source in massive powder processing.

Acknowledgments

This work was partly supported by JSPS KAKENHI Grant Number JP19K03808. This work also was partly supported by Supporting Industry Project, Japan.

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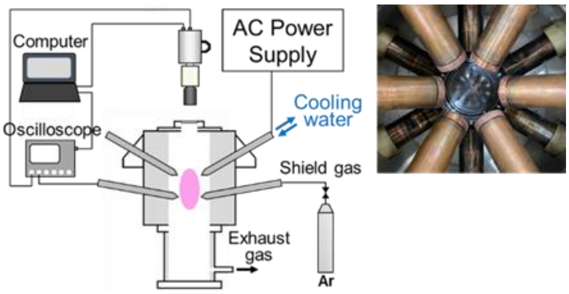

Fig. 2 Schematic diagram of the multiphase AC generator and measurement system arc.

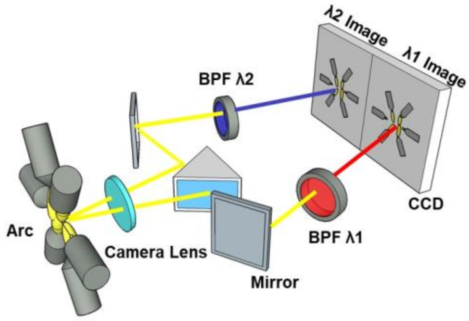

Fig. 3 Schematic image of visualization system with high-speed camera and band-pass filters.

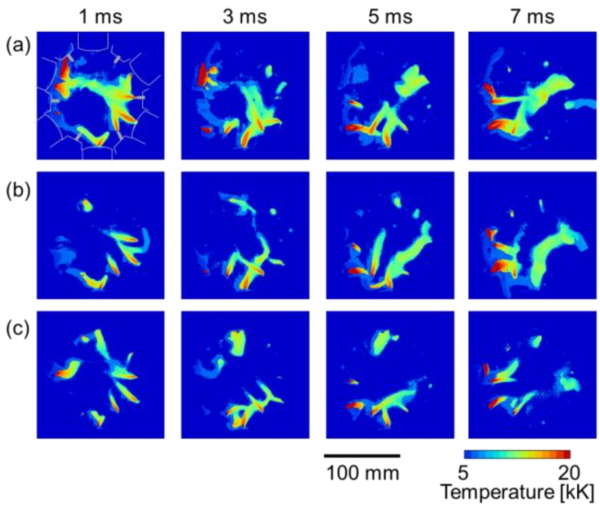

Fig. 4 High-speed visualized temperature distributions of diode-rectified multiphase AC arc at different arc currents; (a) 200 A, (b) 150 A, and (c) 120 A.

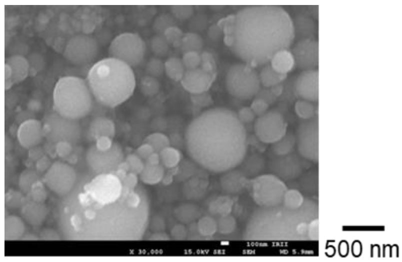

Fig. 5 Representative SEM image of the synthesized Si nanoparticles by multiphase AC arc.