Highly-Controlled Thermofluid Fields by Multi-Flange Installation in Tandem Modulated Induction Thermal Plasmas for High-Rate Nanoparticle Synthesis

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Abstract: This study investigates the control of thermofluid fields in tandem-modulated induction thermal plasma (tandem-MITP) systems by installing additional multi-flanges in the reaction chamber for the synthesis of large quantities of nanoparticles. Numerical simulations reveal that the double-flange configuration significantly enhances entrainment gas flow, increasing nanoparticle production and reducing particle size.

1. Introduction

Nanoparticles and nanomaterials have gained significant attention for next-generation devices across various fields, including electronics, environmental sustainability, and energy applications. High production rates are essential for their industrial application. To address this need, we developed a unique mass-production method using Tandem Modulated Induction Thermal Plasma (Tandem-MITP) with Time-Controlled Feedstock Feeding (TCFF) [1], achieving production rates of several hundred grams per hour. Our previous studies revealed that controlling the thermofluid field, particularly the flow of cool entrainment gas within the chamber, is crucial for enhancing production rates and controlling nanoparticle size [2]. Additionally, machine learning techniques have been employed to optimize numerous control parameters for nanoparticle synthesis [3].

This study investigates the impact of controlling thermofluid fields in the tandem-MITP system through the installation of additional multi-flanges in the reaction chamber. Numerical simulations and experimental studies were conducted to evaluate improvements in production rate and size controllability.

2. Numerical Simulation Condition

We have already developed a numerical thermofluid model to calculate the tandem-MITP field, incorporating electromagnetic fields from tandem coils operating at two different frequencies, the motion and phase changes of feedstock particles, feedstock vapor distribution, and nanoparticle aerosol density distribution [3]. The simulation conditions are as follows: time-averaged input powers of 10 kW each for the upper and lower coils; the upper coil operates at a constant current amplitude, while the lower coil current is amplitude-modulated in a rectangular waveform with a shimmer current level of 50% and a duty factor of 50%. The current study studies the effect of installing additional multi-flanges in the reaction chamber to enhance entrainment gas flow, thereby promoting nucleation and increasing nanoparticle aerosol density.

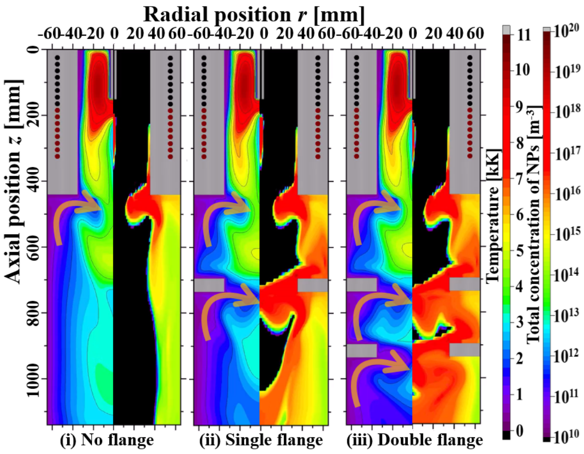

Fig. 1. The temperature fields (left) and nanoparticle aerosol density (right) in the tandem-MITP at t=10 ms with (i) no flange, (ii) single flange and (iii) double flange.

3. Results and Discussions

Fig. 1 illustrates the temperature and nanoparticle aerosol density at the final off-time (t = 10 ms) in a modulation cycle for three configurations: (i) no flange, (ii) single flange, and (iii) double flange. In the no-flange case, the entrainment gas flow is limited to the top of the chamber, leading to moderate cooling and enhanced aerosol density. The single-flange configuration introduces two additional strong cooling gas flows at the flange, which significantly cool the thermal plasma and result in a higher nanoparticle aerosol density. Furthermore, the double-flange setup generates additional entrainment gas flow, enhancing feedstock vapor cooling and tripling nanoparticle production while achieving smaller particle diameters.

References

[1] K.Onda, et al. J.Phys. D: Appl. Phys, Vol.53, No.16, 165201 (2020)
[2] R. Furukawa, et al., J. Phys. D: Appl. Phys., Vol. 55, 044001 (2021)
[3] Y.Tanaka, et al., ISPC-25, 1-P-301 (2023)