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Numerical Study for Influence of Feedstock Feeding Duration on Nanoparticles Synthesis by Modulated Induction Thermal Plasma with Intermittent Feeding Method

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The authors have experimentally found that functional nanoparticles (NPs) can be produced in large quantities by pulse modulated induction thermal plasma (PMITP) and time-controlled feedstock feeding (TCFF) method [1]. Furthermore, for the formation process of Si NPs by this PMITP+TCFF method, a numerical model was also developed [2]. This model can calculate the time-dependent electromagnetic thermofluid field for PMITP, the behavior of the feedstock powder and the nucleation and growth of NPs with considering two-way interactions among the PMITP, feedstock particles and NPs. In this paper, using the developed model, the particle size distribution of synthesized NPs for different feeding time durations of the feedstock for Ar-PMITP was investigated.

In this numerical study, the thermal plasma was regarded as an electromagnetic fluid, and the temperature and velocity fields were calculated using the SIMPLE algorithm by solving the conservation equations for mass, momentum and energy, and the Poisson equation for the vector potential generated by the coil current. The conservation equations for mass, momentum, and energy were solved for individual feedstock particles using the fourth-order Runge-Kutta method. The aerosol general dynamics equation was solved for the formation and transport of NPs by the method of moment (MOM).

For the calculation conditions, Ar sheath gas of 90 slpm was introduced from the top of the torch. Fig. 1 shows the given coil current, the given feed rate of feedstock, and the calculation result of evaporation rate for each condition. The coil current was pulse-modulated, and the ratio of the current amplitude at off-time to the current amplitude at on-time was set to 70%. The modulation period was set to 20 ms, and both on-time and off-time were set to 10 ms [2].Time t=0-10 ms after 20 cycles was set to off-time, and t=10-20 ms was set to on-time. Si feedstock was intermittently supplied from a water-cooled tube in the center of the torch with a carrier gas Ar 4 slpm at a duty ratio of 50, 35 and 25%DF_{valve} with an average feed rate of 1.0 g/min/rad. The ratio of open-time to the feeding modulation period is defined as DF_{valve} (Duty Factor). The average input power is assumed to be 20 kW.

From the result of evaporation rates for each condition, as shown in Fig. 1, the time averaged evaporation rates at 50%DF_{valve}, 35%DF_{valve}, and 25%DF_{valve} were 0.981 g/min/rad, 0.971 g/min/rad, and 0.891 g/min/rad, respectively. This indicates that the evaporation rate is higher when the feedstock feeding time is longer.

Fig. 2 shows the particle size distribution in the computational space near the reaction chamber wall. The particle size distribution was obtained by calculating the time averaged moments of each computational mesh, and then adding the particle size distribution of each computational mesh from the geometric mean particle size and geometric mean volume. From Fig.2, it can be seen that the particle density was higher for 35%DF_{valve} and 25%DF_{valve} feeding time compared to 50%DF_{valve} feeding time. The number density of NPs was the highest for feeding time of 35%DF_{valve}. In the case of 25%DF_{valve}, the nucleation was unlikely to occur because the number density of evaporated feedstock vapor was lower due to lower evaporation rate as shown in Fig. 1. On the other hand, in the case of 50%DF_{valve}, the total evaporation rate was relatively higher as indicated in Fig.1, but the number density of feedstock vapor was lower because the evaporation of feedstock occurs in a wide region instead of local region.

Reference

[1] Y. Tanaka, et al., J. Phys. Conf. Ser., 406, 012001, 2012
[2] Y. Tanaka, et al, The 73rd Annual Gaseous Electronics Conference, GT3.00006, 2020

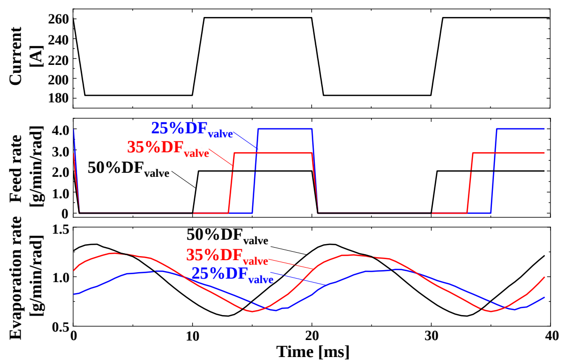

Figure 1 Coil current, feed rate of feedstock and evaporation rate for each condition: 50%DF_{valve}, 35%DF_{valve}, and 25%DF_{valve}.

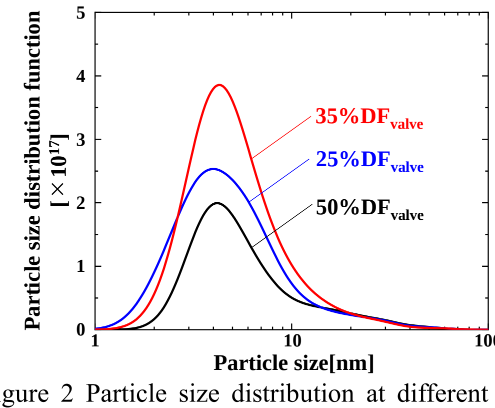

Figure 2 Particle size distribution at different duty factor conditions for feeding.