Numerical Study for Influence of Different Gap Length on Nanoparticles Synthesis by Tandem-Modulated Induction Thermal Plasma

Jingqian Peng[1], Rio Okano[1], Yasunori Tanaka[1], Yusuke Nakano[1], Tatsuo Ishijima[1],
Shiori Sueyasu[2], Shu Watanabe[2], Keitaro Nakamura[2]
[1]Kanazawa University, [2]Nisshin Seifun Group Inc.
e-mail (speaker): pengjingqian@stu.kanazawa-u.ac.jp

We have so far developed the pulse-modulated induction thermal plasma (PMITP) and time-controlled feedstock feeding (TCFF) method to produce large amounts of nanoparticles. For the improvement of the method, a numerical simulation model has been developed, which could calculate the temperature distribution, flow velocity, nucleation frequency, average nanoparticle size and so on for different experimental conditions [1]. Furthermore, we developed the two-coil tandem-type modulated induction thermal plasma (Tandem-MITP) to prevent destabilization of plasma due to raw material injection [2]. In this paper, the gap length *g* between the two coils were studied, and a suitable gap length could benefit the generation of nanoparticles.

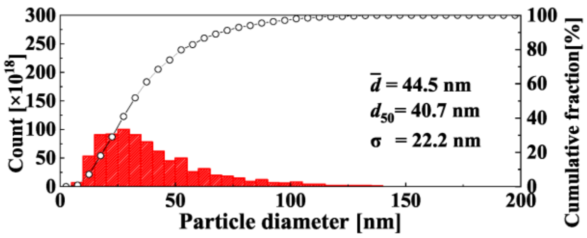
The developed numerical model solves the momentum conservation equations, energy conservation equations, mass conservation equations and Poisson's equations to get the distributions of multiphysics fields. As calculation conditions, the Ar was supplied as sheath gas and carrier gas with 90 L/min and 4 L/min, respectively. The chamber pressure was 300 torr. The Si feedstock powder was supplied with 1.0 g/min/rad intermittently, synchronizing with the coil current. For the upper and lower coils, the average powers were set to both 10 kW. The upper coil current frequency is 420 kHz, while the lower one is 210 kHz. The shimmer current level (SCL) for the upper coil current is 70%, while it is 10% for lower coils. The modulation cycle was 20 ms, in which there is 10 ms for high-current state, while there is 10 ms for low-current state. As comparison, the gap length (*g*) was set as 20 mm, 40 mm, 60 mm, 80 mm and 100 mm.

Fig. 1 shows the calculated particle size distributions. As shown, the sum of the nanoparticle counts for the gap length of 100 mm is the largest, while the cumulative fractions are similar for different *g*'s. Thus, the change in *g* causes the change in nanoparticle amount, while hardly influencing the ratio of particles with different diameters.

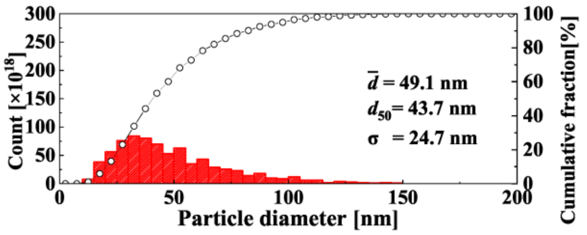
For the distributions of multiphysics fields, the simulation shows that the maximum of the temperature in the torch would be higher for longer *g*, as shown in the left panels in Fig. 2. The area where a higher nucleation frequency could be achieved near the coil would be larger with a longer *g*, as depicted in the right panels in Fig.2.

The higher temperature field would result in more efficient evaporation of silicon feedstock, which would help to nucleate more frequently. At the same time, the higher temperature causes a higher gas flow velocity. This would result nucleated particles transported more broadly. As the gap length g increases, Si vapor is produced at higher concentrations and nucleated at higher frequencies, which would transport them downstream to produce a large number of nanoparticles.

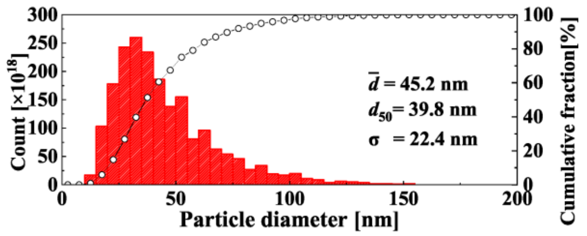
References
[1] R. Furukawa, et al. J. Phys. D: App. Phys. 55.4,044001 (2021).
[2] R. Furukawa, et al. Plasma Chem. & Plasma Process. 42.3, 435-463 (2022).



(a) *g*=20 mm

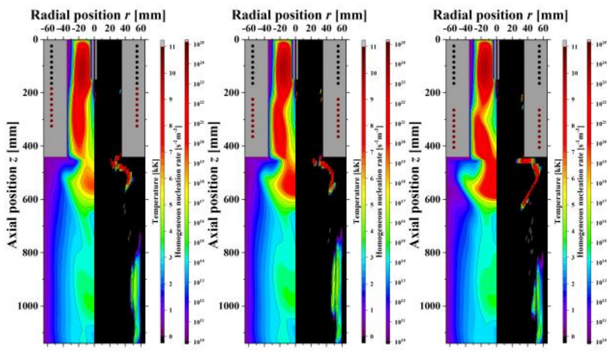


(b) *g*=60 mm



(b) *g*=100 mm

Figure 1 Particle diameter distribution for *g*=20, 60, and 100 mm.



(a) *g*=20 mm (b) *g*=60 mm (c) *g*=100 mm

Figure 2 Two-dimensional gas temperature distributions(left) and nucleation frequency distributions(right) for different gap lengths at *t*=2.5 ms during off-time.