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Continuous synthesis of metal nanoparticles by discharge plasma in gas/liquid slug flow

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1. Introduction

Metallic nanoparticles have been applied to conductive materials, biosensors, photocatalysts and the like because they exhibit optical and electrical properties and catalytic activity which are not found in particles of a larger size. Among them, because silver nanoparticles express properties such as electric field enhancement effect by surface plasmon resonance and antibacterial action which are not found in other nanoparticles, various synthetic methods of silver nanoparticles have been developed so far. In the synthesis method using thermal non-equilibrium plasma, there is an advantage that the size control of particles is easy because particles are reacted in low temperature state [1)]. However, many of those are batch type reactor, thus it is difficult to react uniformly. In this study, we developed a plasma process where discharge can be seen on the interface in gas/liquid slug flow. We applied this process to the synthesis of silver nanoparticles as a new reaction field and tried to synthesize silver nanoparticles uniformly.

2. Experimental

An experimental apparatus diagram is shown in Fig 1. 2.0 mmol / L silver nitrate aqueous solution dissolving starch (0.40 wt %) as dispersing agent on the liquid phase, with argon or helium on the gas phase was supplied from the Y-shaped pipe at the liquid rate of 1.5 mL / min, and gas rate of 0.15 mL/min. Consequently gas-liquid two-phase slug flow was formed, in which gas bubbles was introduced at regular intervals. Afterward, thermal non-equilibrium plasma was discharged on the interface of gas-liquid by applying an AC pulse voltage (± 10 kV) with a frequency of 10 kHz and a pulse width of 10 μsec to the copper foil tape installed on the outer surrounding of glass capillary (ϕ 2.0 mm) in slug flow.

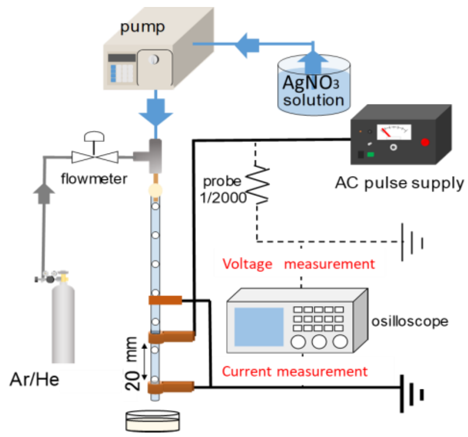

Fig. 1 Schematic diagram of experimental set

3. Result and Discussion

The obtained solution exhibited a transparent yellow color, and an absorption peak was confirmed at a wavelength of 420 nm, which is inherent to silver nanoparticles, by UV-vis spectrophotometer. Furthermore, the existence of spherical silver nanoparticles was confirmed by STEM / EDX. In addition, under the same conditions on the liquid phase, presence of silver nanoparticles was confirmed even when helium gas was used on the gas phase. Comparing the diameters of the silver nanoparticles synthesized for each gas, uniform and fine particles were obtained in the case of helium gas as described in Fig. 2.

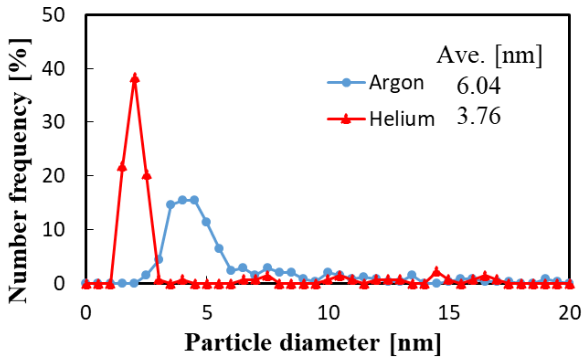

Fig. 2 Comparison of particle’s size depending on gas

One of the reasons for the change in the particle size depending on the introduced gas species is possibly a difference in the amount of H radicals, which is considered as a kind of reducible active species in the plasma reaction. It is known that the maximum volume of unstable nucleus is proportional to the nucleation time in the nucleation process, which is a preliminary step of nanoparticle’s crystallization. Therefore, when the emission spectrum of the plasma generated under each condition was measured by optical spectroscope, it was confirmed that the emission intensity of H radical and Ag atom was higher in the case of argon gas than of helium gas. This suggests that an increase in the nucleus size resulting from an increase in the nucleation time may have an effect on the obtained particle size.

4. Conclusion

It was suggested that this method can be applied to the synthesis of metal nanoparticles as a new plasma process, which can control particle size easily in terms of spatial and temporal stability of discharge conditions.

Reference

1) Heo, Yong Kang, et al. "Synthesis of mono-dispersed nanofluids using solution plasma." *Journal of applied physics* 116.2 (2014): 024302