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Thermal Plasma Synthesis of Amorphous Silicon Nanoparticles for Lithium Ion Batteries

Xiaoyu ZHANG, Kentaro YAMANO, Ririko HAYASHIDA, Hirotaka SONE, Manabu TANAKA, Takayuki WATANABE

Kyushu Univ.

1. Introduction

Lithium ion battery (LIB) is the most important energy storage in modern society. Silicon is a promising material because of high charge storage capacity of 4200 mAh/g that is approximately 10 times higher than graphite as an anode material. However, crystalline silicon undergoes a 400% volume expansion during lithiation process and lead to serious electrode failure mechanisms. Therefore, amorphous silicon nanoparticles attract great interest as anodes material due to their structural characteristics.

Thermal plasmas are expected to synthesize amorphous particles due to its high quenching rate. In this research, induction thermal plasma is used to synthesize the amorphous silicon nanoparticles, and the formation mechanism is investigated.

2. Experimental setup

The experimental setup mainly consists of three parts, RF torch, chamber and filter. The plasma was generated by the RF power supply of 4MHz at 20 kW. Silicon powders with a diameter around 5 μm were injected into torch through the powder feeder by argon carrier gas at a constant powder feed rate of 100 g/min. In order to enhance the quenching for synthesized nanoparticles, a counter flow argon gas was injected as quenching gas at different flow rates. Synthesized nanoparticles were characterized by XRD, TEM, and STEM-EELS.

3. Results and discussion

Figure 1 shows effect of quenching flow rate on the amorphization degree, which was defined and estimated as shown in the following equation.

$$(Amorphization\ \ Degree) = x_{\alpha} / (x_{\alpha} + x_{C}) \qquad (1)$$

where x indicates the mass fraction of the considered species in the prepared nanoparticles. Subscripts of α and C denote amorphous and crystalline phases.

Obtained result shows that higher quenching gas flow rate leads to a higher amorphization degree. This can be explained by two possible reasons. First reason is that the higher quenching rate of the nanoparticles over than 10^6 K/s at higher quenching flow rate. Another reason is the smaller particle diameter, which promotes the amorphous silicon formation. Amorphous phase is thermodynamically preferable when the particle diameter becomes less than 3 nm in the case of silicon [1].

Figure 2 shows the representative TEM images of the synthesized silicon nanoparticles with and without quenching gas. The average diameter of the nanoparticles is 93 nm and 44 nm, respectively. Synthesized particles have a spherical shape with different diameters in both cases. A large amount of nanoparticles with a diameter smaller than 10 nm appears in the case with quenching gas injection.

4. Conclusions

Amorphous silicon nanoparticles were successfully synthesized in induction thermal plasma. The amorphization degree of synthesized nanoparticles can be controlled according to quenching effect.

References

[1] D.K. Yu *et al.,* Phys. Rev. B, **65**, 245417, (2002).

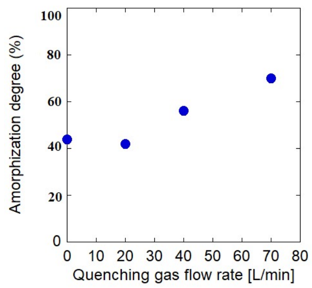

Fig. 1 Effect of quenching gas flow rate on amorphization degree.

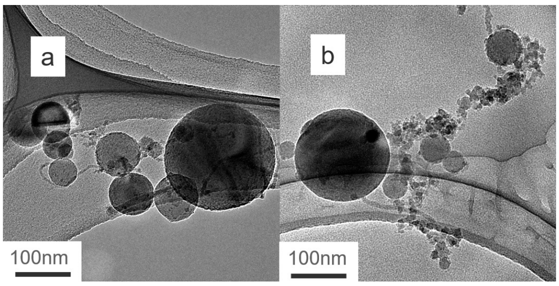

Fig. 2 TEM images of synthesized nanoparticles without quenching gas (a) and with quenching gas at 70 L/min (b).