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High throughput production of silicon nanorod from powder feedstock by plasma flash evaporation

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Silicon nanorods have been produced at high throughputs by the modified plasma flash evaporation using powder feedstock. In this process, Si source and Cu catalyst powder sources are injected separately to a controlled region of the plasma jet to attain vapor and molten state, respectively, so that the reaction environment satisfying the VLS criteria for nanowire growth is created at lower temperature zone leading to a continuous growth of silicon nanorod. The growth rate of silicon nanorod so produce is identified nearly several times faster than the case of the conventional growth by CVD owing potentially to the accelerated Si flux to the molten catalyst under the thermal plasma condition. Based on the growth model considering the particle heating/condensation and directional growth form molten catalyst, the guiding principle to configure the shape and size of silicon nanorod is proposed quantitatively. The effect of these silicon nanorods on the lithium-ion battery will also be discussed.

Silicon in a one dimensional wire/rod form is known to attain high cyclability as a promising high capacity anode of the next generation lithium ion batteries. This is primarily because the electric conductivities is increased and the gaps between nanowires accommodates uniquely the anisotropic dilation as large as 400% during lithiation[1,2]. Such nanowire/nanorod is conventionally grown by the so-called VLS mode in which expensive gas, such as monosilane, is used as Si source and molten catalyst is prepared separately in advance so that the overall nanowire growth process inevitably becomes a batch process and its growth rate is essentially slow[3,4]. This issue needs to be overcome if unique properties effective to lithium-ion batteries are to be used practically. As one potential solution to respond to this technical limitation, we have proposed one step fast growth of Si rod from inexpensive powder feedstock by modifying plasma spraying.

The fundamental idea to establish the VLS mode during a continuous process is as follows. In VLS, Si grows in a form of wire/rod from molten catalyst once it is supersaturated in the catalyst either by cooling at a constant concentration or by excess supply of Si vapor at a fixed temperature. This readily implies that Si needs to be at the vapor state while the catalyst be at the molten state. However, considering the conventional plasma spray step using Si and catalyst metal mixed power feedstock, the catalyst such as Cu melts and evaporates first before Si during heating while Si condenses at higher temperature than Cu during cooling, which does not meet the VLS requirement. Therefore, in this work, Cu is introduced separately to lower temperature zone in the plasma while Si is in the high temperature flame in a same way with the basic PS-PVD, such that molten Cu and vapor Si coexist during process. As a result, successfully as is seen in the SEM-EDS image of Fig.1, the rod shape Si is actually grown from the CuSi alloy catalyst, confirming that the VLS growth is established during rapid plasma spray processing. Also, developing the growth model under the present condition, the growth rate is identified to be as fast as 1 mm/s which is much faster than the conventional SiNW. The size of the molten Cu needs to be reduced to form literally nanowire form, by careful selection of the catalyst raw powders with respect to the temperature profile in the plasma jet used. Nevertheless, it is interesting to note that plasma flash evaporation is a powerful tool to produce not only nanocomposite particles[5] but also the one dimensional structural material at fast rates directly from powder feedstock, which underlines the uniqueness and potential of the plasma flash evaporation.

References

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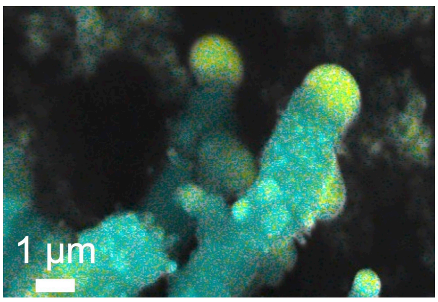

Figure 1. SEM-EDS image of Si rod continuously grown from Cu catalyst during plasma spraying. Green color is Si and yellow is Cu.