Baseline Si Electrode Fabrication and Performance for the Battery for Advanced Transportation Technologies Program

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Project Summary

Baseline Si electrodes were developed and characterized based on Si nanomaterials. Silicon (Si) with a designed nanostructure has attracted much attention as potential anode materials for lithium-ion batteries due to its high gravimetric specific capacity. Because of a resulted poor tap density of Si from the electrode while using nano-sized Si and also from including other additives like conductive carbon and binder, it is difficult to maintain a high loading of active materials at the anode side in lithium-ion batteries.

In this report, we aim to investigate how the thickness of Si-based electrode influences the cycling performance, rate performance and impedance. We also discuss the variation of gravimetric, area and volumetric capacity along with increasing of electrode thickness. It is found that with a thinner electrode of 7 mm the volumetric capacity could reach up to 920 mAh cm^{-3} but a poor area capacity of 0.7 mAh cm^{-2}, while a thicker one of 33 mm enables to provide a high area capacity up to 1.5 mAh cm^{-2} and gives a volumetric capacity less than 500 mAh cm^{-3}. A cell operated under 0 ° C shows a gravimetric capacity of 2000 mAh g^{-1} after 60 cycles.

Electrochemical Performance

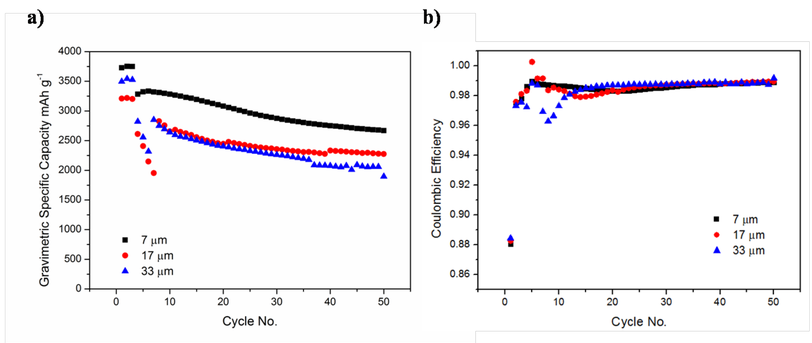


Fig. 1. a) Cycling performance (Gravimetric Specific Capacity vs. Cycle No.) of n-Si/NaCMC/PVA/AB electrodes with different thickness (7 mm, 17mm and 33 mm) and their b) corresponding coulombic efficiency.

Table 1 Thickness, Si loading and porosity of Si electrods

Entry	Thickness	Si Loading	Porosity
1	7 μm	0.24 mg/cm²	65%
2	17 μm	0.44 mg/cm²	72%
3	33 μm	0.74 mg/cm²	78%

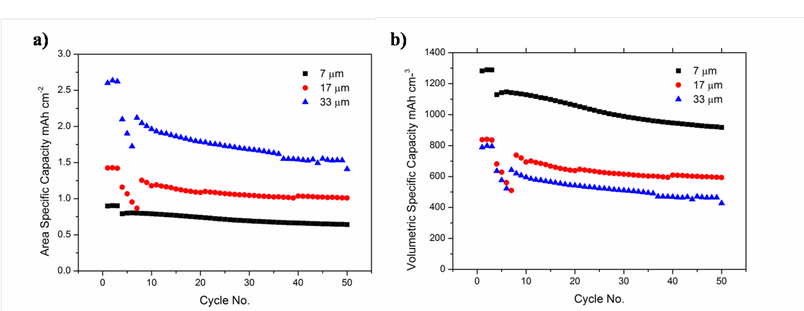


Fig. 2. Cycling performance of n-Si/NaCMC/PVA/AB electrodes with different thickness (7 mm, 17mm and 33 mm): a) area specific capacity vs. Cycle No. and b) volumetric specific capacity vs. Cycle No.

Electrochemical Performance

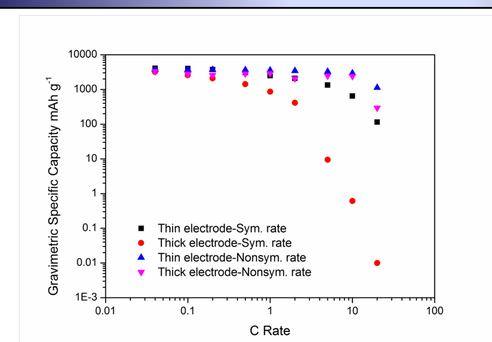
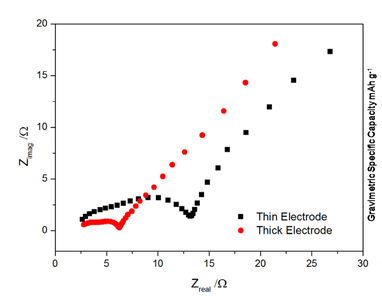


Fig. 3. Symmetric and non-symmetric rate performance of thin and thick electrode at different charge/discharge rates from C/25 to 20C. (1C = 4.2 Ag^{-1}).



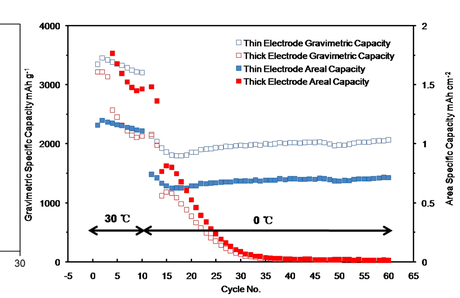


Fig. 4. Cell impedance based on two different thickness electrodes. Impedance was recorded after fifty cycles at C/10, and the rest were recorded 4 h after half-lithiation in the next cycle.

Fig. 5. Cycling performance of n-Si/NaCMC/PVA/AB thin electrode at 30 C (ten cycles) and 0 C (fifty cycles) at C/10 on two different thickness electrodes.

Conclusions and Future Work

A composite electrode containing nano-sized Si, NaCMC and AB was made with different thickness (7 mm, 17 mm and 33 mm). The fabricated cells showed a high gravimetric capacity over 2000 mAh/g after 50 cycles as well as a coulombic efficiency of 99%, indicating the introduce of large surface area nano Si could greatly improve the electrochemical performance of Si-based lithium-ion batteries.

Through the study of symmetric and non-symmetric rate test, Si-based lithium ion battery enable to perform a high specific capacity over 1000 mAh/g at 1C charge/discharge either using thin or thick electrode. Considering various thickness of electrodes having different loadings of Si, the cells performed different level of area capacity and volumetric capacity of Si. It is found that the battery using Si nanoparticles without any structure designing is difficult to reach a high area capacity, which cannot compete with a conventional battery using graphite. In this report, an area capacity up to 2.5 mAh/cm² is achieved at slow charge/discharge rate using a thicker electrode but fade to 1.5 mAh/cm² after 50 cycles at a fast rate. However, volumetric capacity obtained from the same electrode only gave a low value of 420 mAh/cm³ when we tried to push the Si loading up. To sum up, we aim to test the applicability of Si as electrodes in lithium-ion batteries and deliver the information to people who also feel interests on his field that 1) making a stabilized and high gravimetric capacity is not a secret and easy to achieve, but 2) making an applicable battery with both a high area capacity and volumetric capacity needs to be explored.

Ongoing research will focus on finding a scalable and cheap nano or micro-sized Si materials as anodes and making an applicable battery with both high area capacity and volumetric capacity not limited at room temperature but also aimed to low temperature application.

Acknowledgement

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