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Low-cost silicon alloy with an inactive matrix as an anode material for lithium-ion batteries

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Introduction

As lithium ion batteries are becoming a key-enabling technology for versatile applications such as portable devices and electric vehicles, it is highly demanded that they be low-cost, high-energy-density and long-lasting [1-2]. Silicon is one of the best candidates for the anode material but the key issues are its poor cycleability and initial capacity loss [3].

In this paper, a silicon-based anode material with an inactive matrix of low-cost metals that shows high initial capacity and long cycle life will be discussed.

Experimental

The anode material that contains silicon, aluminum and iron was fabricated using a rapid solidification process. Dispersed over the inactive matrix of ternary metal alloy was nano-crystalline silicon.

The morphology and microstructure of the anode were characterized by X-ray diffraction (XRD) and scanning electron microscopy (SEM). Coin full-cells and half-cells were assembled in order to investigate electrochemical performance including capacity, initial efficiency and cycle life. The anode electrode was composed of 80wt% of the as-fabricated material, 10wt% of graphite, 2wt% of conductive additive and 8wt% of binder. NCM was used as the counter-electrode for the full cells and current density was about 3.0mA/cm^2 at 1C. 1.5M $LiPF_6$ in EC:DEC:FEC 5:70:25 was used as the electrolyte.

Results and Discussion

The XRD patterns indicate that the inactive matrix inside the anode material is mostly $Si_3Al_3Fe_2$. Compared to $Si_7Ti_4Ni_4$, the ternary phase of silicon, titanium and nickel that we presented last year, it consumes less silicon so can exhibit a greater capacity using the same amount of silicon. When aluminum and iron was synthesized in the ratio of 3:2, iron silicide ($FeSi_2$) barely formed as in Fig. 1 (a). XRD peaks of the silicide are present in Fig. 1 (b), however, when the ratio is 1:1.

SEM was performed to observe the microstructure of the melt-spun ribbons as in Fig. 2. By optimizing melt-spinning conditions, such as wheel speed and argon pressure inside the chamber, thickness of the ribbons and the crystalline size of silicon can be minimized.

The coin half-cells using the active material that was made under the improved melt-spinning conditions showed initial efficiency of 85.2% in the first cycle at 0.1C and specific discharge capacity of 883mAh/g in the second cycle at 0.2C. Capacity retention after 50 cycles was found to double from around 40% to around 80% at 1C charge/discharge in the coin full-cells when the conditions were improved as in Fig. 3.

Conclusions

The anode material with nano-crystalline silicon dispersed over the inactive matrix of $Si_3Al_3Fe_2$ has advantages of low cost, high initial capacity and long cycle life. More approaches need to be developed and implemented in order to achieve in silicon alloy the stable cycle performance of graphite.

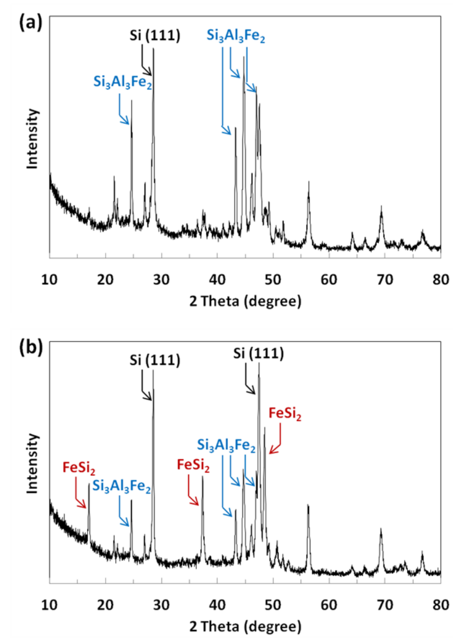

Fig. 1. XRD patterns of the as-fabricated silicon alloy when the ratio of aluminum to iron is (a) 3:2 and (b) 1:1.

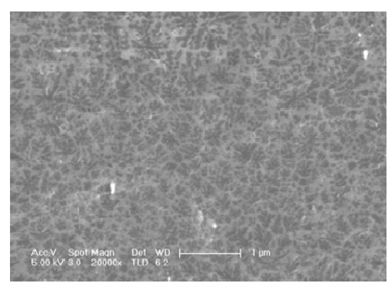

Fig. 2. SEM image of the melt-spun ribbon: the active silicon shows bright and the inactive matrix shows dark.

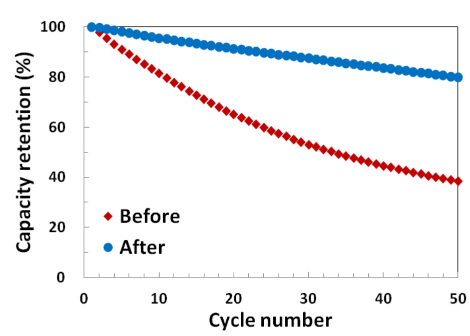

Fig. 3. Capacity retention for the first 50 cycles before and after optimizing the melt-spinning conditions.

Acknowledgements

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References

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