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Effects of particle size on the electrochemical properties of aluminum powders as anode materials for lithium ion batteries

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Abstract

Aluminum powders with different sizes ranging between 59 μm and nano-scale are chosen as anode materials for lithium ion battery. All the samples were characterized by X-ray diffraction (XRD), scanning electron microscope (SEM), particle size analysis, electrical resistivity, ac impedance spectroscopy and galvanostatic cycling. The effects of particle size on the electrochemical properties are investigated. Aluminum powder with the particle size of 37 μm delivers the highest initial charge capacity (Li deintercalation process) of 779.0 mAh/g but cycle life is poor. Powder with 15 μm delivers initial charge capacities of 608.0 mAh/g and possesses relatively good cycleability. Big particle size (59 μm) results in low capacity as well fast capacity fading, and small particle size (under 3 μm) cannot be activated for the compact protective layer.

Keywords: Lithium ion battery; Metal anode; Aluminum; Particle size

1. Introduction

Lithium ion batteries have been widely used as power sources in modern electronic devices because of their high energy and power densities. It is well known that carbon materials have been commercially used as anode materials. However, their relatively low capacity and safety problem urge people to search for new materials with high capacity and long cycle life.

Metals have been investigated as anode candidates for lithium ion battery in recent years, such as Si, Sn, Ag, Bi and Sb [1–7]. Between 1970s and 1990s in the last century, Li–Al alloys have already been studied to replace lithium in rechargeable lithium cells [8–11]. It was also reported by Schleich and co-workers [12] that aluminum appears as a good material as a negative electrode for lithium ion batteries, whose report showed that aluminum thin films with thickness 0.1, 0.3 and 1 μm possess high discharge (Li intercalation process) capacities of 1390, 1090 and 960 mAh/g, respectively. Meanwhile, the charge–discharge curves of aluminum show flat and wide plateaus in the deintercalation and intercalation process, which is a very attractive feature for high capacity anode materials. However, the thin films have huge loss in capacity, whose highest value of coulombic efficiencies is 58%, and only the first cycle information was given and discussed.

Normally, particle size and morphology are important factors which affect the electrochemical performance of the materials. However, only the aluminum with morphology of thin film was studied until now. In the present work, six different sizes of spherical aluminum powders were tested as anode material. The effects of particle size on electrochemical properties of aluminum were investigated.

2. Experimental

All aluminum powders were used as received, labeling as sample **1** (59 μm), **2** (37 μm), **3** (23 μm), **4** (15 μm), **5** (3 μm) and sample **6** (nano). Coin cells were used for electrochemical tests. Slurries prepared were consisted of 60 wt.% aluminum powder, 25 wt.% acetylene black and 15 wt.% polytetrafluoroethylene (PTFE) binder. Lithium metal was used as a counter electrode, and 1 M $LiPF_6$ solution in a 1:1 (volume ratio) mixture of ethylene carbonate (EC) and dimethyl carbonate (DMC) was used as electrolyte. The cells were assembled in an Argon-filled glove box (Mikrouna-China Super 1220/750). Cells were charged and discharged galvanostatically with current density 100 mA/g in the range of 0.001–1.5 V at 25 °C. The electrochemical properties were examined using Neware cell test system.

The X-ray power diffraction (XRD) measurements were carried out with a Shimadzu XRD6000 diffractometer with Cu $K\alpha_1$ radiation ($\lambda = 1.54056$ Å). The scanning electron microscope (SEM) images were performed by means of

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Table 1
Particle size of all samples

	1	2	3	4	5	6
D_{10} (μm)	25.063	19.029	10.191	5.453	1.537	0.301
D_{50} (μm)	58.528	36.682	22.653	14.991	3.140	0.879
D_{90} (μm)	127.539	67.573	47.374	31.113	6.096	2.195

Hitachi 400 SEM. The particle size analysis was carried out by Malvern Matersizer 2000. The electrical resistivities were obtained by means of liner sweep voltammetry with CHI660A. The ac impedance measurements were performed using CHI660A by applying an ac voltage of 5 mV amplitude in the frequency range 10 mHz–1 MHz.

3. Results and discussions

The particle size and particle size distributions of all samples are shown in Fig. 1 and Table 1. The average particle sizes of the samples **1**–**6** are 58.528, 36.682, 22.653, 14.991, 3.140 and 0.879 μm, respectively. Fig. 2 illustrates the SEM images of

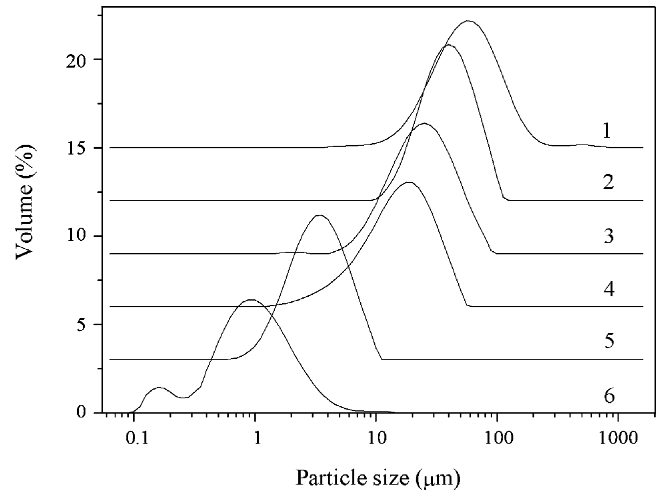

Fig. 1. The particle size distribution of various aluminum samples.

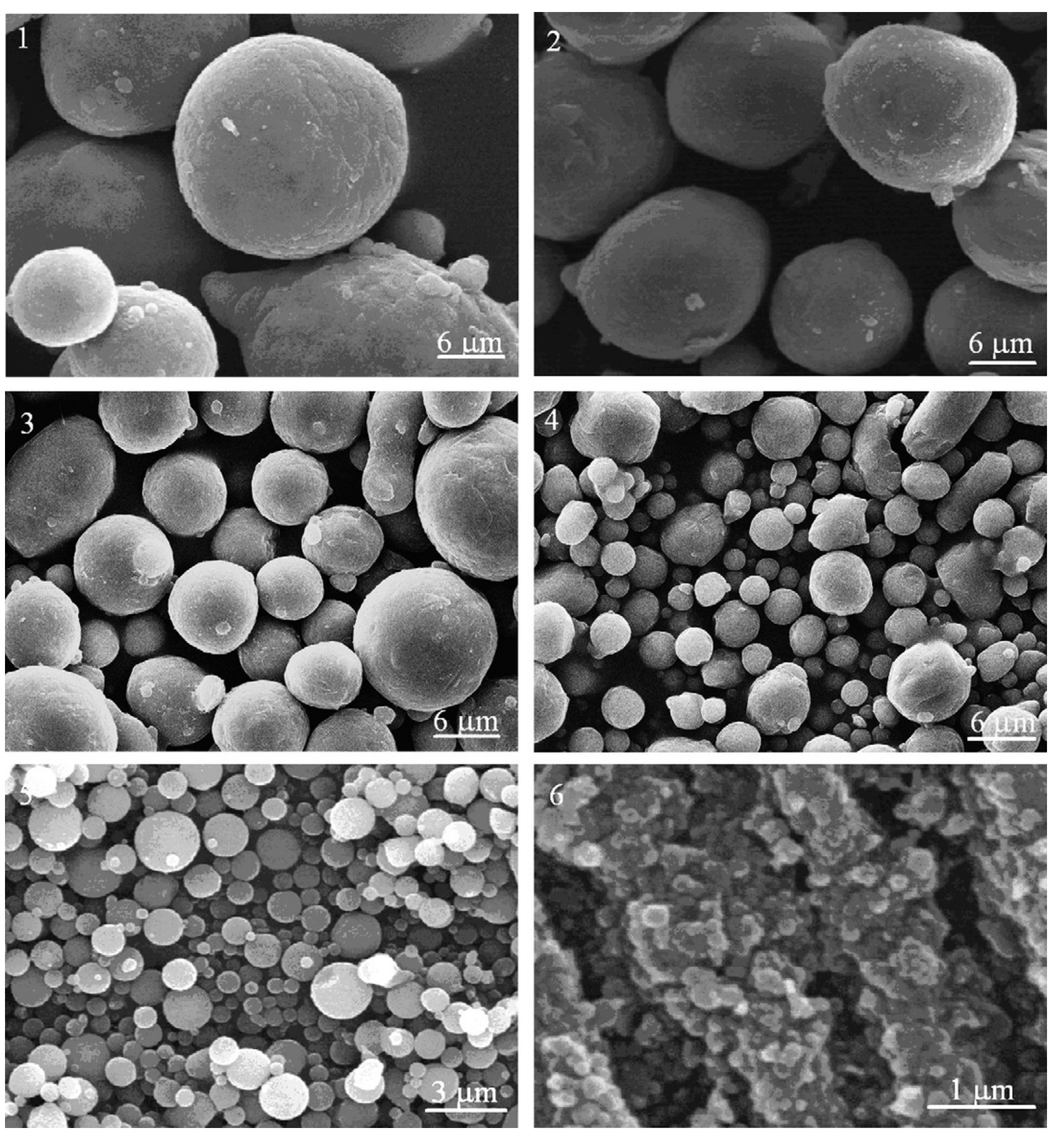

Fig. 2. SEM images of all samples.