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Morphology Control and Cycling Stability of Sn Nanostructures and Sn/RGO Composites as Lithium-Ion Battery Anodes

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Crystalline tin (Sn) nanostructures and tin/reduced graphene oxide (Sn/RGO) composites have been synthesized with different morphologies via a facile reduction method. The effects of the morphology and particle size on the cycling stability of Sn and Sn/RGO as Li-ion battery anodes were investigated. For crystalline Sn, different morphologies of nanosheets, nanorods, nanospheres and nanoparticles were obtained by adjusting the reaction conditions, such as the reaction temperature and precursor. The associated electrodes exhibited a rapid capacity decay and weak cycling stability. However, small-sized Sn particles displayed a relatively more stable cycling performance than that of the larger-sized particles. Compared with Sn, the cycling stability of the Sn/RGO composites was greatly improved with a long cycling life, even at a larger current density. For instance, the Sn/RGO electrode, in which spherical Sn nanoparticles with diameters of ~ 5 nm are uniformly dispersed on the RGO surface, delivers a reversible discharge capacity of 355 mAh g⁻¹ at the end of 50 cycles at 200 mA g⁻¹.

Keywords: Tin; reduced graphene oxide; nanostructures; Li-ion battery anodes

1. INTRODUCTION

Graphite anodes have been widely used in commercial Li-ion batteries (LIBs) since the 1990s. However, because of a low theoretical capacity (LiC₆: 372 mAh g⁻¹) and poor rate performance, these anodes are unable to meet the increasingly rigorous demands of LIBs [1-4]. Among various available anode materials, metallic tin (Sn) anodes have long been considered an attractive alternatives due to their high theoretical capacities (Li_{4.4}Sn: 993 mAh g⁻¹), low cost, environmental benignity, high electrical conductivity and moderate operating voltage [5, 6]. However, tin electrodes often suffer from large lithiation/delithiation associated volume changes, which results in a rapid capacity decay and weak cyclability during cycling processes [7]. To overcome these drawbacks, many approaches have been adopted.

Previous studies have suggested that reducing the sizes of the Sn particles to the nanometer range can provide a short Li⁺ diffusion length, and increase morphology stability during discharge/charge cycles, which lead to a high Li⁺ diffusion rate and long cycling lifetime [8]. However, the aggregation of Sn nanoparticles (Sn NPs) during cycling then becomes a major issue due to the huge specific surface energy of the ultrafine active nanoparticles. To solve this problem, Sncarbonaceous composites combining Sn NPs and a carbonaceous matrix, such as a nano-Sn filled in carbon nanotube [9], a Sn/C composite nanofiber [10], a rambutan-like Sn@C nanoarchitecture [11], a carbon coated Sn nanocomposite [12], and Sn NPs dispersed in porous carbon [13], have related their promising potential. In these hybrids, the carbonaceous matrix acts as a barrier to prevent the aggregation of Sn NPs, and provides a void space where the Sn NPs can experience a volume change. Recently, graphene as a new member of carbon family was considered to be a good matrix because of its large specific surface area that can provide active sites for the Sn NPs, superior electrical conductivity and excellent mechanical flexibility. Therefore, Sn/graphene composites have been attracted much attention and many synthesis methods have been applied, such as microwave reduction, chemical vapor deposition and a combination of different approaches [14-19]. Herein, we report a facile one-step reduction method to synthesize crystalline Sn nanostructures and tin/reduced graphene oxide (Sn/RGO) composites. The morphology of the obtained materials was controlled by changing the reaction conditions. The discharge/charge performance of the Sn nanostructures and Sn/RGO composites, as well as the relationship between the morphology and cycling stability have been investigated and discussed.

2. EXPERIMENTAL

2.1. Materials

 $SnCl_2 \cdot 2H_2O$ (Analytical reagent, Sinopharm Chemical Reagent Co., Ltd.), $C_{12}H_{25}SO_4Na$ (Chemical pure, Shanghai Lingfeng Chemical Reagent Co., Ltd.), NaBH₄ (Analytical reagent, Nanjing Xiezun Chemical Co., Ltd.), and absolute ethanol (Analytical reagent, Shanghai Titan Scientific Co., Ltd.) were used as the precursor, protecting agent, reducing agent, and solvent, respectively, for the synthesis of the Sn nanostructures. NaOH (Analytical reagent, Shanghai Titan Scientific Co., Ltd.) was used in some cases to regulate the reduction rate and yield of Sn by producing $Sn(OH)_2$ precipitates as the precursor. Graphene oxide was obtained from natural graphite flakes (> 99.8%, Nanjing XFNANO Materials Tech Co., Ltd.) by a modified Hummers method [20].

2.2. Synthesis

2.2.1. Synthesis of the Sn nanostructures at different temperatures

2 mmol SnCl₂•2H₂O, 0.25 mmol C₁₂H₂₅SO₄Na were dissolved in 50 mL absolute ethanol, and then the solution was placed at a given temperature (0 °C by using an ice bath, 30 °C, 40 °C, 50 °C, 60 °C and 70 °C via applying an oil bath) under magnetic stirring with an Ar flow in a three-neck flask.

Subsequently, excess NaBH₄ was dissolved in 50 mL absolute ethanol and then added to the precursor system. Grey products were immediately observed. After 30 min, the precipitates were collected via centrifugation, washed with deionized water and absolute ethanol, and then dried at room temperature in a vacuum oven.

2.2.2. Synthesis of the Sn nanostructures with different amounts of NaOH

During the synthesis, 2 mmol $SnCl_2 \cdot 2H_2O$ with a specific amount of NaOH (4 mmol or 8 mmol) was dissolved in 50 mL absolute ethanol to form a white colloidal suspension. The colloidal suspension was heated to 70 °C under magnetic stirring with an Ar flow in a three-neck flask. Then, 50 mL absolute ethanol containing excess NaBH₄ was added, and a white colloidal suspension gradually turned to dark grey. After 30 min, the precipitate was collected, washed and dried.

2.2.3. Synthesis of the Sn/RGO composites

For the synthesis of the Sn/RGO composites, 2 mmol SnCl₂•2H₂O, 0.02 g as-synthesized graphene oxide and a certain amount of NaOH (0 mmol, 4 mmol or 8 mmol) were first dissolved in 50 mL absolute ethanol. In addition, the system was heated to 70 °C under magnetic stirring with an Ar flow in a three-neck flask. Then, NaBH₄ dissolved in 50 mL absolute ethanol was added. After 30 min, the dark grey precipitates were collected, washed and dried. The obtained composites were referred to as Sn/RGO-I (without NaOH), Sn/RGO-II (4 mmol NaOH) and Sn/RGO-III (8 mmol NaOH).

2.3. Characterization

Powder X-ray diffraction (XRD) patterns of the samples were collected on a D/MAX-2550 diffractometer using Cu-*K* α radiation over a 5° $\leq 2\theta \leq 80^{\circ}$ range with a step size of $\Delta 2\theta = 0.02^{\circ}$. Fieldemission scanning electron microscopy (FESEM) measurements were performed on a Nova Nano SEM-450 microscope. For high-resolution transmission electron microscopy (HRTEM), a JEOL JEM-2100F electron microscope was used. X-ray photoelectron spectroscopy (XPS) measurements were conducted on an ESCALAB 250Xi spectrometer using Al-*K* α radiation.

2.4. Electrode preparation and electrochemical characterization

To evaluate the electrochemical characteristics, the electrodes were prepared by mixing 80 wt% active powders, 10 wt% conductive acetylene black and 10 wt% polyvinylidene fluoride (PVDF) binder dissolved in n-methyl pyrrolidinone (NMP) to form a homogeneous slurry. The mixture was painted onto a copper foil and dried under vacuum at 80 °C for 24 h. The active material loading density of the electrode was ca. $0.9 - 1.0 \text{ mg cm}^{-2}$. The coin-type half-cells (2016) were assembled in an argon-filled glove box. A Li metal foil was utilized as the counter electrode; a non-aqueous solution of LiPF₆ (1 M) in a 1:1:1 of ethylene carbonate (EC), diethyl carbonate (DEC), and dimethyl carbonate

(DMC) was used as the electrolyte; and a Celgard 2325 was applied as the separator. The discharge/charge cycles were recorded using a LAND CT2001A battery test system (Wuhan LAND electronics Co., Ltd.) at various current densities in a voltage range of 0.005–1.5 V.

3. RESULTS AND DISCUSSION

3.1 Sn nanostructures



Figure 1. XRD patterns of metallic tin synthesized at different temperatures. The reference pattern of tetragonal Sn (JCPDS no. 04-0673) is also shown.

Fig. 1 shows the XRD patterns of the products synthesized at different temperatures (0 °C, 30 °C, 40 °C, 50 °C, 60 °C and 70 °C). All the diffraction peaks located at $2\theta = 30.6^{\circ}$, 32.0° , 43.9° , 44.9° , 55.3° , 62.5° , 63.8° , 64.6° , 72.4° , 73.2° and 79.5° can be assigned to the (200), (101), (220), (211), (301), (112), (400), (321), (420), (411) and (312) crystal planes of tetragonal tin (JCPDS no. 04-673), respectively, indicating the formation of pure metallic Sn. The yield of Sn (the weight ratio of the experimental and theoretical output) for all of the samples was approximately 60 %.



Figure 2. SEM images of metallic tin synthesized at (a) 0 °C, (b) 30 °C, (c) 40 °C, (d) 50 °C, (e) 60 °C and (f) 70 °C.



Figure 3. HRTEM images and SAED patterns of metallic tin synthesized at (a), (b) 0 °C and (c), (d) 70 °C.

The SEM images, as shown in Fig. 2a-f, reveal the morphology of metallic Sn synthesized at different temperatures. The grey products prepared at 0 °C in an ice bath exhibit rectangular nanosheets (length $\approx 1 \mu m$), as shown in Fig. 2a. The HRTEM image clearly reveals the morphology of one nanosheet with particle agglomerates on the surface (Fig. 3a). The SAED patterns along the [001] direction (Fig. 3b) confirm the single-crystalline nature of the metallic Sn phase of the nanosheet [21]. When the reaction was performed at 30 °C or 40 °C in an oil bath, irregular rod-like structures with different sizes (length < 1 μ m, diameter < 200 nm) were obtained (Fig. 2b and c). However, as the reaction temperature increased to 50 °C and 60 °C, the nanorods gradually disappeared, but cobblestone-like nanoparticles were formed (Fig. 2d and e). At 70 °C, the obtained cobblestone-like

nanoparticles are more regular and homogeneous (approximate 200 nm in size) and behave multiple facets demonstrated by SEM image (Fig. 2f). The HRTEM image (Fig. 3c) and corresponding SEAD patterns along [100] direction (Fig. 3d) indicate the single-crystalline metallic Sn phase [21]. As the temperature rises from 0 °C to 70 °C, the morphology of Sn changes from nanosheets to nanorods and then into cobblestone-like nanoparticles. The results suggest that the formation of the high-dimensional Sn nanostructures requires lower energies, but the formation of the low-dimensional nanostructures requires higher energies.



Figure 4. SEM and HRTEM images of metallic tin synthesized with different amounts of NaOH: (a), (b), (c) 4 mmol and (d), (e), (f) 8 mmol.

A common method to change the morphology and size of Sn nanomaterials is the use of surfactants, such as polyvinylpyrrolidone (PVP). The sizes of the Sn NPs were controlled from 15 to 89 nm by adjusting the amount of PVP [22]. Herein, the amount of NaOH in the precursor system regulated the reduction rate and yield of Sn and also controlled the morphology and size of the Sn nanostructures. In the presence of NaOH, Sn^{2+} first reacted with OH⁻ to form white precipitates identified as Sn(OH)₂, and then was reduced by NaBH₄ to form metallic Sn. The reaction was performed at 70 °C for 30 min. Due to the different amounts of NaOH (4 mmol or 8 mmol), the molar ratio of SnCl₂ to NaOH was 1:2 and 1:4 resulting in approximately 90 % and 30 % Sn yields, respectively. The SEM and HRTEM images in Fig. 4 show the morphologies and crystalline structures of metallic Sn synthesized with different amounts of NaOH. When 4 mmol NaOH was used in the precursor system (the molar ratio of Sn^{2+} to OH^{-} was 1:2), the metallic Sn particles are spherically shaped with different diameter sizes ranging from tens of nanometers to hundreds of nanometers, as indicated by the SEM image (Fig. 4a). The HRTEM image (Fig. 4b) also reveals the spherical shape of the products. Fig. 4c shows the lattice fringes of one spherical particle. The spacing between the adjacent lattice planes is 0.29 nm, which correspond to the (200) planes of tetragonal Sn [22]. As the amount of NaOH increased to 8 mmol (the molar ratio of Sn^{2+} to OH⁻ was 1:4), the as-synthesized Sn exhibits spherical nanoparticle agglomerates, as displayed in the SEM image (Fig. 4d). The HRTEM image shows regular spherically shaped nanoparticles with a homogeneous size of approximately 40 nm (Fig. 4e). The lattice fringes in the HRTEM image (Fig. 4f) reveal the crystalline nature of the Sn NPs. The spacing between the adjacent lattice planes is 0.29 nm, corresponding to the (200) planes of tetragonal metallic Sn [22].

3.2 Sn/RGO composites

Fig. 5 is the XRD patterns for GO and the Sn/RGO composites synthesized with different contents of NaOH. For GO, the peak centred at $2\theta = 9.1^{\circ}$ is consistent to a layered structure with a *d*-spacing of 0.97 nm. In addition, for the Sn/RGO composites, the sharp diffraction peaks demonstrate the formation of crystalline tetragonal Sn (JCPDS no. 04-0673). The peaks corresponding to RGO are not clearly observed perhaps due to the higher amount and better crystallinity of tin.



Figure 5. XRD patterns of GO and the Sn/RGO composites synthesized with different amounts of NaOH. The reference pattern of tetragonal Sn (JCPDS no. 04-0673) is also shown.

Details of the chemical changes during the reduction of GO functionalized with Sn were further investigated by XPS. Fig. 6 shows the C 1*s* XPS spectra of GO and the Sn/RGO composites. For GO, the C 1*s* spectra can be fitted with three peaks centred at 284.6 eV, 286.7 eV and 288.1 eV, which are ascribed to nonoxygenated carbon (C–C), epoxy carbon and carbonyl carbon (C=O) [23], respectively. The C 1*s* spectra of the Sn/RGO composites exhibit two peaks at 284.6 eV and 285.9 eV associated

with nonoxygenated carbon (C–C) and hydroxyl carbon (C–O), respectively [23]. Compared with GO, the Sn/RGO composites show a strong suppression of the oxygen-containing components in their C 1*s* XPS spectra. These results indicate an efficient reduction of the oxygen-containing functional groups in GO by NaBH₄ to form RGO.



Figure 6. C 1*s* XPS spectra of GO and the Sn/RGO composites synthesized with different amounts of NaOH.

The HRTEM images in Fig. 7 reveal the morphology of GO and the Sn/RGO composites. The as-synthesized GO sheets used as the matrix for the Sn particles are large layers with a clear wrinkled structure (Fig. 7a). Fig. 7b shows an HRTEM image of the Sn/RGO composite (Sn/RGO-I) synthesized without NaOH. It is observed that the Sn particles are distributed on the RGO nanosheets with different sizes ranging from tens of nanometers to hundreds of nanometers. The lattice fringes are clearly observed, as shown in Fig. 7c, and a lattice spacing of 0.29 nm corresponds to the (200) planes of tetragonal Sn [22], which indicates the formation of single crystalline Sn particles. Additionally, the substrate is identified as RGO with a lattice spacing of 0.35 nm, which is consistent with the (002) planes of the RGO nanosheets [18]. The HRTEM images of the Sn/RGO composite (Sn/RGO-II) synthesized with 4 mmol NaOH display spherical particle (diameter \approx 100 nm) agglomerates distributed on the RGO nanosheets (Fig. 7d and e). Fig. 7f shows lattice fringes with a spacing of 0.29 nm that is consistent with the (200) planes of tetragonal Sn [22]. When the amount of NaOH was increased to 8 mmol, the HRTEM images of Sn/RGO-III reveal that the Sn spherical nanoparticles with diameters of ~ 5 nm are uniformly dispersed on the surface of the large wrinkled RGO layers (Fig. 7g and h). These Sn NPs exhibit a lattice spacing of 0.29 nm and 0.28 nm for the (200) and (101)

planes, respectively [22, 24], as shown in Fig. 7i. It is observed from the images that an increase in the NaOH amounts from 4 mmol to 8 mmol in the precursor results in a decrease in the density and size of the Sn particles on the RGO surface because the decrease in both the reduction rate and yield of Sn.



Figure 7. HRTEM images of (a) GO and the Sn/RGO composites synthesized with different amounts of NaOH: (b), (c) 0 mmol, (d), (e), (f) 4 mmol and (g), (h), (i) 8 mmol.

3.3 Electrochemical properties

The electrochemical properties of metallic Sn and the Sn/RGO composites were evaluated using discharge/charge cycles. Fig. 8a shows the cycling performance of Sn nanostructures synthesized at different temperatures over 50 cycles at a constant current of 200 mA g⁻¹. The first discharge capacity of each electrode is 934 mAh g⁻¹, 839 mAh g⁻¹, 817 mAh g⁻¹, 976 mAh g⁻¹, 1119 mAh g⁻¹ and 972 mAh g⁻¹. After the first cycle, the discharge capacity values decrease to 724 mAh g⁻¹, 653 mAh g⁻¹, 665 mAh g⁻¹, 707 mAh g⁻¹, 784 mAh g⁻¹, and 763 mAh g⁻¹, and the initial cycle efficiency values are approximately 77.5%, 77.8%, 81.4%, 72.4%, 70.1% and 78.5%, respectively. The irreversible initial capacity loss could be due to the formation of a solid electrolyte interphase layer [25, 26] and a decrease in tin oxide contamination on the surfaces of the Sn particles [27]. With the cycling process, all of the Sn electrodes display a rapid capacity decay during the cycles with discharge capacities of 25 mAh g⁻¹, 41 mAh g⁻¹, 34 mAh g⁻¹, 57 mAh g⁻¹, 49 mAh g⁻¹ and 51 mAh g⁻¹ at the 50th cycle. The coulombic efficiency of each electrode is 83.8%, 81.4%, 82.4%, 75.5%, 78.8% and 81.8% for the first cycle, and then increases during the second cycle to 95.3%, 87.3%, 94.3%, 93.8%, 94.6% and 96.7%, respectively. The results suggest that the morphology of the Sn nanostructures do not obviously affect

the initial capacity loss. However, the electrode of Sn nanoparticles synthesized at 70 °C displays a more stable cyclability in the 20 cycles than that displayed by the other Sn electrodes, perhaps due to the regular shape and uniform size of the particles.

The OH⁻ concentration can regulate the reduction rate and therefore influence the morphology of obtained Sn materials as well as the electrochemical performances of corresponding electrodes. Fig. 8b depicts the cycling performances of the electrodes over 50 cycles at a constant current of 200 mA g⁻¹. For all of the Sn electrodes, a large first discharge capacity is observed, followed by a fast capacity decay, and the cyclability can be influenced by morphology to a certain extent. The electrode with ~ 40 nm-sized Sn nanoparticles synthesized with 8 mmol NaOH exhibits better cycling stability than that of the other two Sn electrodes because of the small nanoparticle size.

The electrochemical properties of the Sn/RGO composites synthesized with different amounts of NaOH were measured on the corresponding Sn/RGO-I (without NaOH), Sn/RGO-II (4 mmol NaOH) and Sn/RGO-III (8 mmol NaOH) electrodes. Fig. 8c presents the voltage profiles of the pure GO and Sn/RGO electrodes in the first cycle. In addition, Fig. 8d shows their cycling performances over 50 cycles at a current density of 200 mAh g⁻¹. For the pure GO electrode, the first discharge capacity is approximately 802 mAh g^{-1} . Then, the discharge capacity decreases to 124 mAh g^{-1} at the second cycle, resulting a low initial cycle efficiency of 15.5%, but remains stable at further cycles. For the Sn/RGO-I, Sn/RGO-II and Sn-RGO-III electrodes, the first discharge capacity is 1148 mAh g⁻¹, 1018 mAh g⁻¹ and 1064 mAh g⁻¹, respectively. At the second cycle, the discharge capacities decrease to 802 mAh g^{-1} , 629 mAh g^{-1} and 458 mAh g^{-1} with initial cycle efficiencies of approximately 70.0%, 61.8% and 43.0%, respectively, which are much higher than those of the GO electrode but lower than those of the Sn electrodes. The coulombic efficiencies of pure GO, Sn/RGO-I, Sn/RGO-II and Sn-RGO-III electrodes are 10.0%, 59.0%, 52.7% and 34.6%, respectively, for the first cycle and becomes constant be nearly 100% after the 50th cycle. The large irreversible initial capacity loss and low first coulombic efficiency of the GO electrode is very likely due to the irreversible reaction of Li ions with the defects on the surface of GO and the high surface area of GO, which increased the contact area between the electrode and the electrolyte, resulting in more SEI formation in the first discharge [28]. Because of the same reasons, the Sn/RGO electrodes also exhibit a large initial capacity loss and a low first coulombic efficiency. However, after 50 cycles, the discharge values of the Sn/RGO-I, Sn/RGO-II and Sn-RGO-III electrodes are 175 mA h g⁻¹, 239 mA h g⁻¹ and 355 mAh g⁻¹, respectively. These values are much higher than those obtained with the Sn electrodes (< 50 mAh g^{-1} after 50 cycles), better than those attained with Sn/C [29] and comparable to those obtained with the Sn/graphene [14] composites but poorer than those values acquired with Sn/C [30] and Sn/graphene sandwich composites [18] (Table 1). The results indicate that the cyclability of the Sn/RGO electrodes is improved compared to that of the Sn electrodes due to the existence of RGO layers. Fig. 8e illustrates the rate capability test results for the Sn/RGO-I, Sn/RGO-II and Sn-RGO-III electrodes. The assembled cells were tested at a current density of 200 mA g⁻¹ for the first 50 cycles and then at increasing current densities from 200 to 1000 mA g⁻¹. Among the Sn/RGO composites, Sn-RGO-III electrode displays the best cyclability because of the homogeneity and small size of the Sn NPs on the RGO sheets. As shown in the curve, the Sn/RGO-III electrode delivers a reversible discharge capacity of 355 mAh g⁻¹ at the end of 50 cycles at 200 mA g⁻¹. In addition, a reversible capacity of 209 mAh g⁻¹

is obtained at the end of 50 cycles with a current density of 500 mA g^{-1} . When the current density increased to 1000 mA g^{-1} , the electrode still exhibits a reversible discharge capacity of 138 mAh g^{-1} after 50 cycles. Additionally, as the current density returned to 200 mA g^{-1} , a discharge capacity of 272 mAh g^{-1} is restored.



Figure 8. Cycle performance of the Sn electrodes synthesized (a) at different temperatures (b) with different amounts of NaOH. (c) Voltage profiles and (d) cycle performance of GO and the Sn/RGO composite electrodes at 200 mA g⁻¹. (e) Rate capability of the Sn/RGO composite electrodes at various current densities.

| Materials | Synthesis method | Electrochemical performance | | Ref. | |
|-------------|--|-----------------------------|--------|---------------------------|-----------|
| | | Current | Cycle | Capacity | |
| | | density | number | retention | |
| Sn | One-step reduction method | 200 mA g ⁻¹ | 50 | $< 50 \text{ mAh g}^{-1}$ | This work |
| Sn/C | Synthesized by annealing | 100 mA g ⁻¹ | 50 | 200 mAh g^{-1} | [29] |
| Sn/graphene | Microwave reduction | 100 mA g ⁻¹ | 50 | 400 mAh g^{-1} | [14] |
| Sn/C | Calcination under argon | 100 mA g^{-1} | 50 | 450 mAh g^{-1} | [30] |
| Sn/graphene | SnO ₂ /C/SnO ₂ @C treated by | 2 A g^{-1} | 50 | 650 mAh g^{-1} | [18] |
| sandwich | annealing process | | | | |
| Sn/RGO-III | One-step reduction method | 200 mA g ⁻¹ | 50 | 355 mAh g ⁻¹ | This work |

Table 1. Electrochemical performance of Sn, Sn/C and Sn/graphene LIB electrodes

4. CONCLUSIONS

Sn nanostructures and Sn/RGO composites have been successfully synthesized by a reduction method via a facile one-step process. The reaction temperature and OH⁻ concentration are found to be important factors in the morphology of the obtained materials. The Sn electrodes exhibit a large first discharge capacity but low cyclability. The electrochemical performances of these electrodes are influenced by morphology and particle size. Compared with Sn, the Sn/RGO composite electrodes display a larger irreversible initial capacity loss, which may arising from the irreversible reaction of Li ions with defects on the surface of RGO and more SEI formation. However, the cyclability of the Sn/RGO composite electrodes has been significantly improved, because the RGO layers can be a good matrix to prevent the aggregation of Sn particles. The morphology and density of the Sn/RGO composite electrodes. Therefore, combining Sn with RGO is a good opportunity to optimize the cyclability of Sn-based Lion battery anodes; however, the development of a simple process to control the surface modification of the RGO sheets and the morphology of the Sn NPs remains a challenge.

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