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One-pot Hydrothermal Synthesis of Nickel Cobaltite for High-Performance Supercapacitor Applications

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Abstract

Hierarchical nickel cobaltite (NCO) nanoneedles arrays have been synthesized *via* a facile one-pot hydrothermal synthesis combined with post-annealing treatment. The nanoneedles array possess a relatively high surface area which facilitate the diffusion of electroactive species and consequently, enhance the capacitance performance. When evaluated as supercapacitor electrode materials, the NCO nanoneedles array was able to produce a high specific capacitance of 168 F/g at current density of 1 A/g.

1. Introduction

With the scientific and technological enhancements in modern society, clean and renewable energy materials and devices are urgently demanded due to the increasing concern for the energy crisis and environmental pollutions [1]. However, the energy output from these materials is sporadic, and demanding high performance energy storage to store the energy for sustainable consumption.

Supercapacitor, an electrochemical energy storage device plays a crucial role for the efficient energy storage of solar and wind energy [2]. It has the advantages of rapid charge/discharge capability, long service life and low production cost. However, the performance of a supercapacitor is highly determined by the properties of electrode materials. Although carbon-based materials have been widely used in supercapacitor manufacturing, the relatively low specific and volumetric capacitance have limited their practical use in high voltage devices [3].

Recently, the emergence of pseudocapacitive material with higher power density and specific capacitance have drawn intensive attention in creating a high-performance supercapacitor. Spinel nickel cobaltite (NCO), is an economic, environmental friendly and easily synthesized transitional-metal oxide, which have been employed in various kinds of pseudocapacitive materials [4]. In this study, we have developed a one-pot hydrothermal synthesis of NCO and used it as an electrode material in high-performance supercapacitor applications.

2. Objectives

This research aims to synthesize NCO nanoparticles *via* one-pot hydrothermal synthesis method and apply these NCO nanoparticles in high-performance supercapacitor electrode material.

3. Methodology

4 M of $Ni(NO_3)_2.6H_2O$ and 8 M of $Co(NO_3)_2.6H_2O$ were dissolved in distilled water, followed by the addition of 15 M of urea at room temperature. Then, the mixture was transferred into a 50 ml Teflon-lined stainless-steel autoclave. The well-cleaned carbon cloth was immersed in the mixture, and the autoclave was kept at 120°C for 6 h. After that, the autoclave was allowed to cool, and the product supported carbon cloth was washed by ethyl alcohol. Lastly, the sample was dried and annealed at 400°C for 2 h.

4. Results

Structural Morphology

The morphology of the as-synthesized NCO nanostructure observed using a FESEM reveals a uniform distribution of nanoneedles on the carbon cloth fibers. It can be clearly seen that the growth of the NCO nanoneedles are large area and remarkably uniform which provide clear information about the detail morphology of the nanoarrays (Fig. 1a). Further observation of the higher magnification image (Fig. 1b) reveals that numerous NCO nanoneedles grew tidily and closely on the carbon fiber surface and possess a high aspect ratio. Interestingly, without the support of carbon cloth, these NCO nanoneedle tends to self-agglomerate into a bulk allium flower-like structure (Fig. 1c) with diameter about 5 μm. From the high magnification image (Fig. 1d), these bulk NCO nanoflowers are composed of numerous small nanoneedles radially grown from the center with a length of about 2 μm. It was expected that both morphologies might have high reactive surface area due to the hierarchical arrays and facilitate the access of electroactive species to their interface and consequently, could provide high specific capacitance [5].

Electrochemical Performances

To justify that the as-synthesized NCO nanostructure may have potential application in high performance-supercapacitors, the NCO decorated carbon cloth electrode was configured in two-electrode system to evaluate their capacitance performance. The cyclic voltammetry (CV) analysis for the as-synthesized NCO nanoneedle were studied at different scan rates ranging from 5 mV/s, 10 mV/s, 50 mV/s and 100 mV/s in a potential range of 0 to 0.8 V (*vs.* Ag/AgCl) and the corresponding CV curves were shown in Fig. 2a. From the CV curve, the peak current density increases with the increase scan rate, proving the pseudocapacitive nature of the NCO nanoneedle arrays. Moreover, a pair of redox peak can be found at different scan rate and the intensity become larger at slower scan rate. This phenomenon indicates that charge storage mechanism of the NCO nanoneedles is mainly contributed by the reversible Faradaic reaction. Since the redox reaction occurs through the insertion-desertion of electroactive species, at slower scan rate, the diffusion of ions from the electrolyte can enter almost every reactive area of the NCO electrode [6].

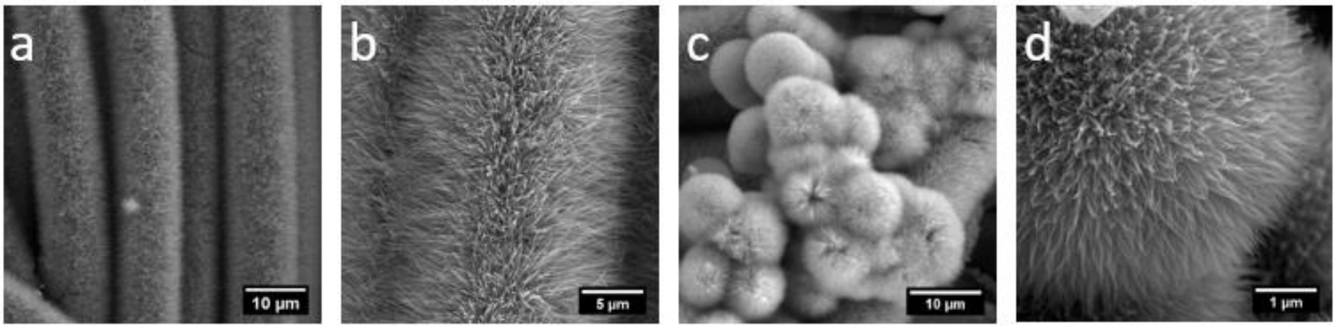

Fig. 1 FESEM images of NCO nanoneedles at low (a) and high (b) magnification and bulk NCO nanoflowers at low (c) and high (d) magnification.

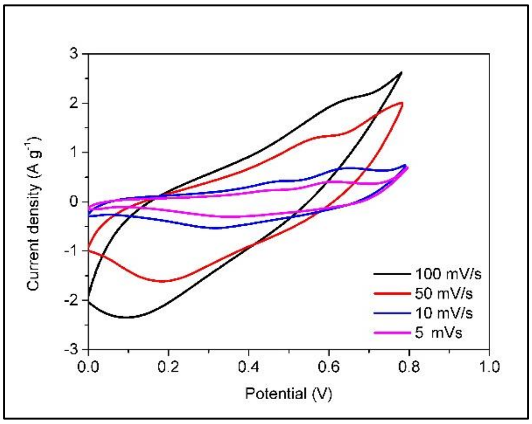

Fig. 2 CV profile of NCO nanoneedles electrode at different scan rate measured using a two-electrode cell configuration.

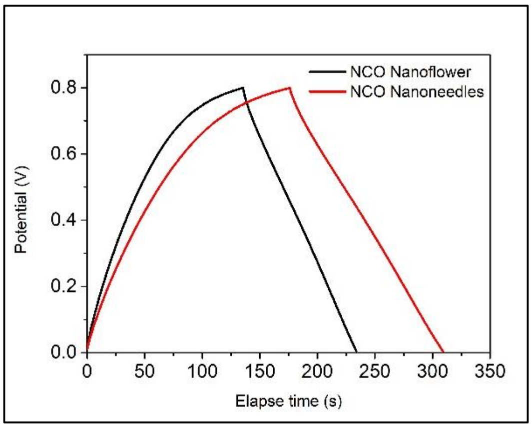

Fig. 3 Galvanostatic charge/discharge profile of NCO nanoneedles and nanoflowers.

In order to get more information about the charge/discharge ability of the as-synthesized NCO electrode, the galvanostatic charge-discharge study were conducted at potential window of 0 to 0.8 V. Fig. 3 shows the comparison of the charge/discharge profile for both the NCO nanoneedle and the bulk NCO nanoflower at a current density of 1 A/g. It is clearly seen that the charge and discharge time for NCO nanoneedles are longer compare to bulk NCO nanoflowers. It is suggested that thee bulk NCO nanoflower possess a higher internal resistance whereby the diffusion pathway of the electroactive species is highly hindered by the dense architecture. The specific capacitance calculated form the NCO nanoneedle array are 168 F/g, which is 30% higher compared to NCO nanoflower.

5. Conclusion

In conclusion, we have successfully synthesized NCO nanoneedles array through a facile one-pot hydrothermal synthesis. The as-synthesized NCO nanoneedles possess superior pseudocapacitive behavior with high specific capacitance and excellent charge/discharge performance. Our findings indicate that the nanoneedles array of NCO is highly desirable in the application of advance electrode materials compared to the bulk flower morphology.

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