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Facile synthesis of ultrathin nickel hydroxides nanoflakes on nickel foam for high-performance supercapacitors

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ABSTRACT

Ultrathin $Ni(OH)_2$ nanoflakes grown on nickel foam have been prepared via a facile hydrothermal route without adding any additional nickel sources and further investigated as a binder-free electrode for high-performance supercapacitors. Benefiting from high conductivity and enough spaces between the nanoflakes in combination with high surface area, the $Ni(OH)_2$ nanoflakes show high-capacitance performance with a specific capacitance of 2342 F g^{-1} at a charge and discharge current density of 2 mA cm^{-2} and 1100 F g^{-1} at 8 mA cm^{-2} with a good cycling ability (80.4% of the initial specific capacitance remains after 2000 cycles). These results show that $Ni(OH)_2$ nanoflakes with this cost-effective synthesis route and distinguished electrochemical performance combined with the flexible nickel foam substrate are very promising for the next generation of high-performance supercapacitors.

1. Introduction

With the ever-growing power and energy demands in modern consumer electronic devices and electric vehicles, the development of high-performance, light-weight and environment friendly energy storage devices has attracted tremendous attention. Among the various storage technologies, supercapacitors are being extensively investigated due to their interesting characteristics of fast rechargeability, high power performance, long cycle-life and environment-friendliness. Supercapacitors store energy using either ion adsorption (electrochemical double layer capacitors) or fast surface redox reactions (pseudocapacitors) [1–3]. Various materials such as transition metal oxides, metal hydroxides and polymeric materials have been explored for pseudocapacitor application [4–7]. In recent years, nickel hydroxide as one of the most promising candidates has received much attention for its high theoretical specific capacitance (2082 F g^{-1} within 0.5 V), low cost and improved environmental compatibility [8–11].

It is well known that the performance of an electrode material depends not only on the microstructure but also the conductivity of the electrode. Nickel foam, as a commercial material with high porosity, good electric conductivity, excellent chemical stability and desirable 3D structure, can be the electrode substrate material of choice. It would not only reduce the diffusion resistance of electrolytes but also enhance the facility of ion transportation and maintain the very smooth electron pathways in the very rapid charge/discharge reactions. In this communication, we demonstrate a facile and cost-effective approach to design and fabricate ultrathin $Ni(OH)_2$ nanoflakes on Ni foam as binder-free electrode for high-performance supercapacitors. In this facile method, $Ni(OH)_2$ nanoflakes are obtained through hydrothermal processing of nickel foam in a solution of NaOH and H_2O_2. Benefiting from ultralow thickness, enough spaces between the nanoflakes, and direct contact with substrate as well as high surface area, the $Ni(OH)_2$ nanoflakes on Ni foam electrode exhibit a very high capacitance and excellent cycling ability. Undoubtedly, the design of free-standing $Ni(OH)_2$ nanoflakes electrode demonstrated in our work offers a promising strategy for the fabrication of high-performance electrodes for supercapacitors.

2. Experimental

Materials synthesis: All of the chemicals used were of analytical grade and used without further purification. In a typical experiment nickel foams with the size of 4×2 cm^2 were cleaned using a 1 M HCl solution in an ultrasonic bath for 20 min in order to remove the possible oxide layer, and followed by deionized ethanol and water. Then the Ni foam was immersed into 80 mL solution containing 15 mL H_2O_2 and 0.05 M NaOH, and all of them were transferred to a 200 mL Teflon-lined stainless-steel autoclave, and maintained at 150 °C for 6 h and then allowed to cool to room temperature. The resulting Ni foam was rinsed with distilled water and ethanol and dried at room temperature.

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In order to determine the active mass, the hydrothermal treated Ni foam was reduced in a tube furnace at 700 °C for 5 h under a constant H_2 flow rate of 120 sccm. Based on the change of weight before and after reduction, the active mass of $Ni(OH)_2$ was obtained. The $Ni(OH)_2$ nanoflakes grown from the nickel foam are about 1.6 g cm^{-2}.

Characterization: The phase of the electrode was examined by X-ray diffraction (XRD) analysis (PW-1800 system). The microstructure and morphology were examined using a scanning electron microscope (LEO 1550 field emission SEM) and a high resolution transmission electron microscope (JEOL 4000 EX).

Electrochemical measurement: Cyclic voltammetry (CV) curves and constant charge–discharge tests were carried out using a three-electrode configuration. The cyclic voltammetry curves were obtained in a potential range between 0 and 0.5 V at different scan rates, and the charge/discharge curves were obtained by cycling from 0 to 0.48 V at different current densities in 1 M KOH aqueous electrolyte. The cyclic stability was evaluated by charge–discharge measurements at a current density of 10 mA cm^{-2}.

3. Results and discussion

Fig. 1(a) shows typical SEM image of the Ni foam indicating that the smooth surface of the 3D framework is cross-linked with considerable and uniform wrinkles, which would provide a high porosity and a high specific surface area. After the hydrothermal treatment, the surface was covered by a highly porous cross-linked structure with pore diameter ranging from 30 to 300 nm (Fig. 1b and c). The interconnecting network is made up of nanoflakes with thickness of about 40 nm. The TEM image in Fig. 1(e) shows that the $Ni(OH)_2$ presents wrinkled paper shape. The corresponding selected area electron diffraction (SAED) pattern (Fig. 1(f)) shows that the disperse rings are well indexed to the crystal planes of

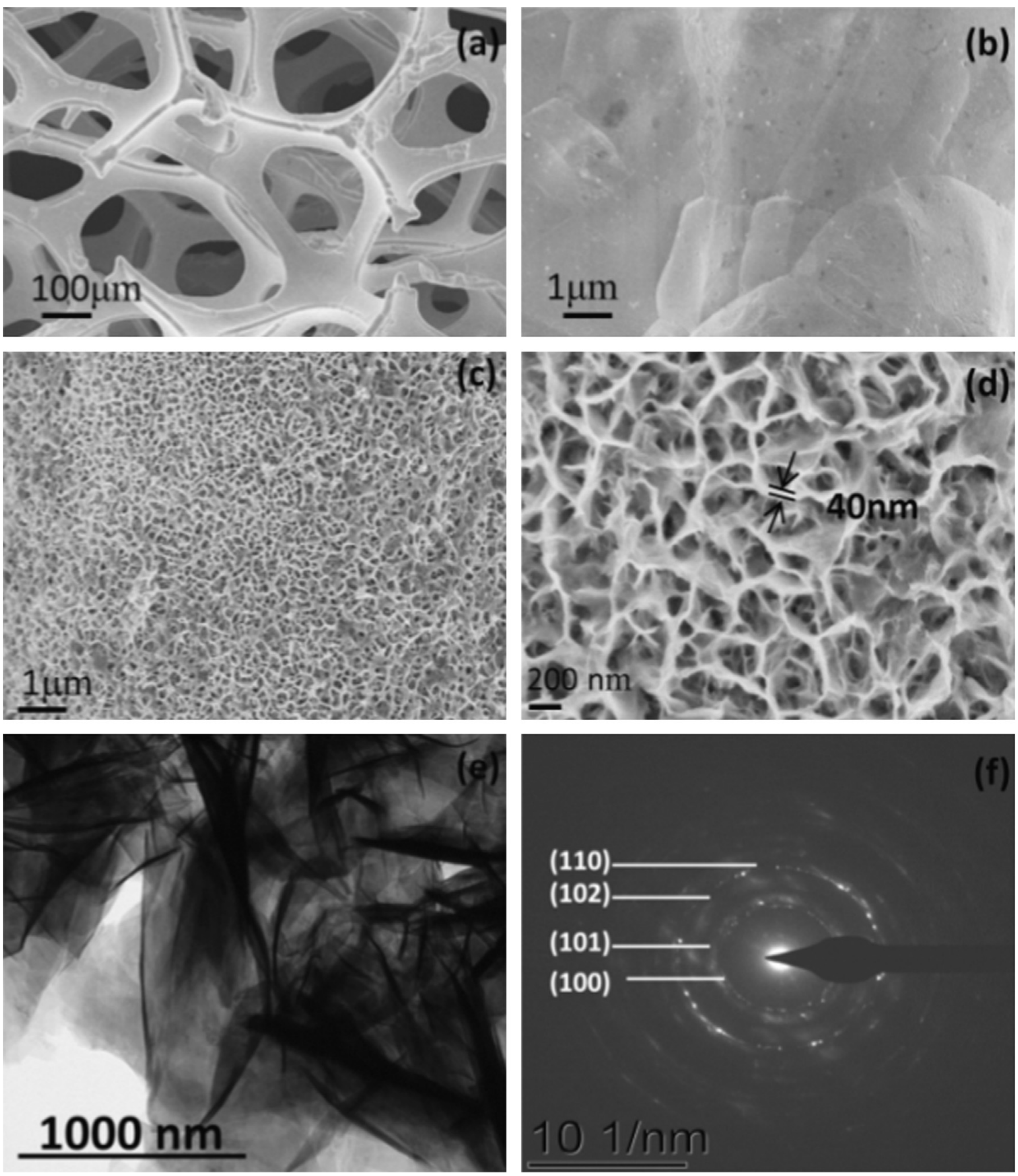

Fig. 1. SEM images of (a,b) nickel foam, (c,d) $Ni(OH)_2$ nanoflakes grown from nickel foam, TEM images (e) and SAED pattern (f) of $Ni(OH)_2$ nanoflakes.