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One-step hydrothermal synthesis of two-dimensional cobalt sulfide for high-performance supercapacitors

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ABSTRACT

Q2 We report a simple strategy to prepare 2-dimensional cobalt sulfide by the one-step hydrothermal process. The cobalt sulfide sample has a microstructure of interconnected sheets. As the electrode material for supercapacitors, the layered cobalt sulfide film exhibits superior performances with high specific capacitances (1314 F g^{-1} at 3 A g^{-1}) as well as excellent cycle life (less than 8.3% decrease in specific capacitance after 500 cycles at 3 A g^{-1}), making it suitable for high-performance supercapacitor application.

1. Introduction

Supercapacitor has received considerable attention due to its fast recharge ability, long cycle life, high power performance and environment-friendly merit [1–4]. It is well-accepted that the capacitance and charge storage of supercapacitors greatly depend on the electrode materials. Two-dimensional (2D) nanomaterial has been considered as one of the most promising materials due to its permeable channel and high specific surface areas [5].

Layered transition-metal chalcogenides, such as WS_2, MoS_2, and VS_2, have been established as a new paradigm for energy storage [6]. They are composed of metal layers and sulfur layers and stacked together by weak Van der Waals interactions. This kind of materials are expected to act as an excellent functional material because the 2D electron–electron correlations among metal atoms would be helpful in enhancing planar electric transportation. Recently, layered transition-metal chalcogenides have been explored as a new type of supercapacitor material and exhibited good performance, such as the polypyrrole/MoS_2 composites [7], the MoS_2–graphene composites [8] and copper sulfide nanoplatelets [9].

In this work, we developed a simple strategy to prepare cobalt sulfide (CoS) sheet via one-step hydrothermal process. The CoS sample presented an ideal material platform due to its synergic properties of metallic nature and layered characteristic, offering great potential as high-performance supercapacitor electrode.

2. Experimental

The CoS sheet was prepared as follows: 0.3 mM $CoCl_2 \cdot 6H_2O$ and 0.6 mmol L-cysteine were firstly dispersed in 60 mL deionized water. Then the mixture was vigorously stirred for 30 min. After that, the mixture was transferred into a 100 mL Teflon-lined stainless steel autoclave and heated at 160 °C for 6 h. After cooling, the CoS was collected by filtration, washed with deionized water and absolute ethanol for three times, and dried in vacuum at 60 °C. Functional groups of the L-cysteine molecule, such as $-NH_2$, –COOH and –SH, have a strong tendency to coordinate with Co^{2+} to form a complex. With increased reaction time, the strong coordination bonds between the hydrosulfide group and Co^{2+} could weaken the S–H bond and further break it due to the high reaction temperature to form CoS sheets.

The morphologies of the sample were recorded on a JEM 2100 transmission electron microscope (TEM) and a Hitachi S-4800 scanning electron microscope (SEM). The electrochemical tests were performed on a CHI 660D electrochemical workstation using a three electrode cell comprising an Ag/AgCl electrode as reference, Pt wire as counter and cobalt sulfide based electrode as the working electrode. Working electrodes were prepared by mixing electroactive material, carbon black and poly(tetrafluoroethylene) in a mass ratio of 75:15:10 to obtain a slurry. The slurry was then pressed onto the nickel foam substrates (1 cm × 1 cm) and dried at 80 °C for 6 h. The specific capacitance was calculated according to the galvanostatic charge–discharge curve as follows:

$$C = It/\Delta Vm \quad (1)$$

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where C, I, t, ΔV, and m are the specific capacitance, current, discharge time, potential window and mass of the electroactive material, respectively.

3. Results and discussion

The SEM image of CoS sample exhibits the overlapped sheet-like subunits structure in Fig. 1a. The 2D architecture of the sample is helpful to increase the specific area of the sample and form an interconnected conducting network between the sheets, which facilitates rapid electronic transport in electrode reactions. To further specify the microstructure of the CoS, the TEM image is shown in Fig. 1b, and the CoS sample displays densely packed arrangement of sheets with irregular sizes.

The X-ray powder diffraction (XRD) pattern recorded for CoS sheets is shown in Fig. 1c. The crystalline peaks appearing at 35° and 48.7° correspond to (200) and (220) planes of CoS, respectively. No characteristic peaks from other impurities are observed in the XRD pattern, indicating that the sample is highly pure. The CoS sheets are further characterized by XPS. As shown in Fig. 1d, the predominant elements in the sample are Co, S, C and O.

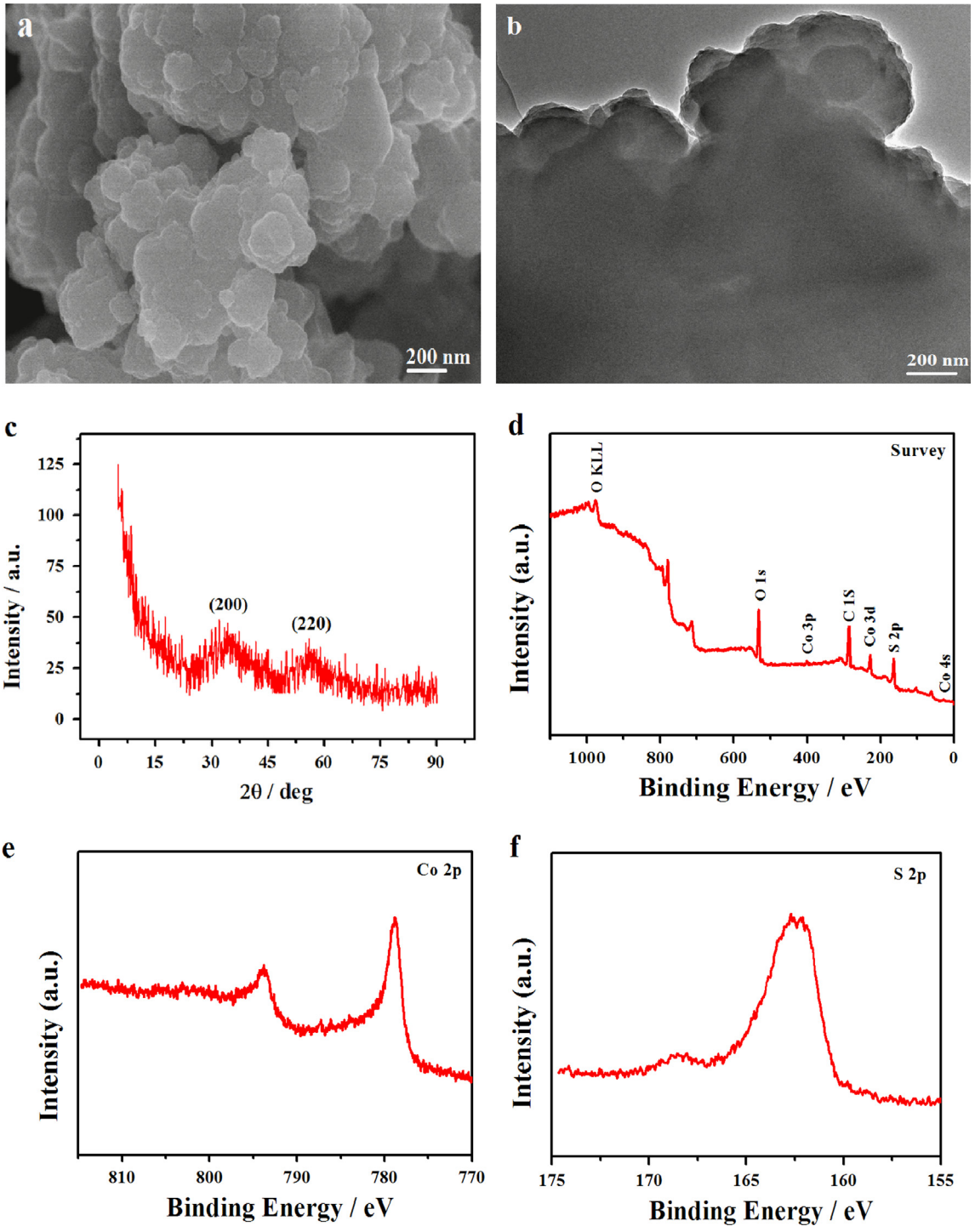

Fig. 1. SEM (a) and TEM (b) images of the CoS sheets; XRD patterns of the CoS sheets (c); XPS survey spectra of the CoS sheets (d); high-resolution spectra for Co 2p (e) and S 2p (f).

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