High rate capability of mesoporous NiWO₄-CoWO₄ nanocomposite as a positive material for hybrid supercapacitor

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Abstract

Nickel-based materials are promising positive electrode for hybrid supercapacitor due to their high theoretical specific capacity. The main obstacle preventing their practical applications is the low conductivity which limits rate capability of supercapacitors. Considering the good rate capability of CoWO₄ and the high specific capacity of NiWO₄, we synthesize a series of mesoporous NiWO₄-CoWO₄ nanocomposite with different Co/Ni molar ratios by a chemical co-precipitation method, and the materials were fully characterized by XRD, XPS, FESEM, TEM and N₂ adsorption-desorption measurements. Impressively, the nanocomposite shows a large surface area of 150.7 m² g⁻¹, which resulting in the enhanced electrochemical performance. In specific, the NiWO₄-CoWO₄ electrode with a Co/Ni molar ratio of 2:8 has the highest specific capacity of 196.7 C g⁻¹ at 0.5 A g⁻¹. Compared to individual NiWO₄ and CoWO₄, it also exhibits improved rate capability which decreases less than one third of the initial value as the current is increased 20 times. Finally, we fabricate a NiWO₄-CoWO₄//AC hybrid supercapacitor whose storage energy density is as high as 30.1 Wh kg⁻¹ even at a large power density of 200 W kg⁻¹. This work provides a novel way to fabricate electrode materials with high electrochemical performance for supercapacitors and other energy storage devices.

Keywords: Supercapacitor; Electrode material; Metal oxide; Nanocomposite; Rate capability

1 Introduction

Supercapacitors have attracted worldwide interests due to their high power density, fast charge–discharge rate, excellent cycle stability and environmental safety [1, 2]. The main challenge for their commercial applications is the limited energy density. In recent years, numerous efforts have been devoted to improve the energy density of supercapacitors without sacrificing their power density and rate capability, such as developing new electrode materials and electrolytes, as well as ingenious device design [3–5]. The development of hybrid supercapacitor consisting of a battery–type Faradaic electrode and a capacitor–type electrode has been found to be an effective approach to increase the energy density of supercapacitors, which will simultaneously holds the advantages of both supercapacitors and batteries.

High performance electrode materials are crucial to improving the performance of hybrid supercapacitors. It is well known that the commonly used electrode materials are classified into the following categories: carbon–based materials [6–9], transition metal oxides [10–14] and conducting polymers, etc.) [15–17]. Ideally, electrode materials must have high specific capacity, good rate capability and excellent cycle stability in order to obtain high energy density and large power density. Due to the multiple oxidation states and high theoretical specific capacity, transition metal oxides appear to be a good choice as positive electrode for high performance hybrid supercapacitor. Unfortunately, the electrochemical behavior of metal oxides is severely restricted by their poor electrical conductivity, especially the rate capability and power performance. To solve this problem, it is crucial to enhance the kinetics of ion and electron transport within the electrode and the electrode/electrolyte interface [18]. Therefore, metal oxide materials with proper pore structure and good electrical conductivity are highly desirable.

Previous studies have shown that ternary metal oxides have better electrical conductivity and higher electrochemical activity compared with their monometallic oxide counterparts [19]. For example, NiCo_2O_4 [20], NiMoO_4 [21], MnWO_4 [22], $\text{Ni}_3\text{V}_2\text{O}_8$ [23], NiWO_4 [24–26], CoWO_4 [26, 27] and their based–composite [28], have been widely employed as positive electrodes for hybrid supercapacitors. It has been found that Ni–based materials have high specific capacity but poor rate capability and cycle stability, while Co–based materials have high rate capability and better cycle stability but low specific capacity [21, 23]. Therefore, it would be beneficial to design a new type of composite materials which can utilize the advantages of both Ni–based and Co–based oxides for hybrid supercapacitor.

Generally, metal tungstates oxides present great potentials in the applications of dielectric ceramics [29], solar water oxidation [30], Li–ion batteries [31], supercapacitors [32–34], etc. Moreover, it has been proposed that the incorporation of W atoms is able to increase the conductivity of transition metal oxides [25, 35]. Consequently, NiWO_4 and CoWO_4 appear as good candidates for fabricating electrodes with high electrochemical performance. In the current work, mesoporous $\text{NiWO}_4\text{--CoWO}_4$ nanocomposite was synthesized through a facile chemical co–precipitation method under mild conditions and used as the positive electrode for hybrid supercapacitor. Owing to the good conductivity, high specific surface area and small particle size of $\text{NiWO}_4\text{--CoWO}_4$ electrode, the assembled asymmetric device can deliver a maximum energy density of 30.1 Wh kg^{-1} at a power density of 200 W kg^{-1} , which show an improved performance than their NiWO_4 (25.3 Wh kg^{-1} at 400 W kg^{-1}) and CoWO_4 (12.0 Wh kg^{-1} at 400 W kg^{-1}) counterparts, as well as high rate capability and long cycle life.

2 Experimental

2.1 Synthesis of NiWO₄–CoWO₄ nanocomposite

All chemical reagents were analytical grade and used without purification. Stoichiometric amounts of Na₂WO₄·2H₂O, CoCl₂·6H₂O and NiCl₂·6H₂O were used to prepare NiWO₄, CoWO₄ and NiWO₄–CoWO₄ nanocomposite via a simple chemical co-precipitation method. Typically, three transparent solutions were obtained by dissolving 10 mmol of Na₂WO₄·2H₂O in 20 mL H₂O (solution A), x ($x = 0, 2, 4, 6, 8, 10$) mmol of CoCl₂·6H₂O in 10 mL H₂O (solution B), and y mmol ($y = 10 - x$) of NiCl₂·6H₂O in 10 mL H₂O (solution C). Then solution A was added dropwise to solution B under vigorous stirring at 70 °C and kept stirring for 3 h. Afterwards, solution C was added dropwise to the above suspension and continuous stirring at 70 °C for another 3 h. Finally, the precipitate was separated by centrifugation, rinsed five times with 50 mL of deionized water for 6 min, and dried at 70 °C for 12 h.

2.2 Material characterizations

The morphology and microstructure of the samples were characterized by field-emission scanning electron microscope (FESEM, JSM-6701F, JEOL, Japan), transmission electron microscope (TEM, Tecnai G20, FEI, USA), N₂ adsorption-desorption isotherms (Micromeritics ASAP 2020 analyzer, USA), X-ray diffraction patterns (XRD, Rigaku D/MAX 2400 diffractometer, Japan) and X-ray photoelectron spectrometer (XPS, ESCALAB 250Xi, Thermo Scientific, UK) using Mg-K α radiation under a pressure of 5×10^{-9} Torr.

2.3 Electrochemical measurements

Commercial activated carbon (AC, Nanjing JCNANO Tech. Co. Ltd., China) was used as negative electrode without further treatment. The working electrodes were prepared by pressing mixtures of the active material, acetylene black, conducting graphite and polytetrafluoroethylene (PTFE)

binder (weight ratio of 80: 7.5: 7.5: 5) onto nickel foam collector, then dried at 70 °C for 12 h and pressed at 10 MPa. Each electrode contained 4.0 mg of the active material and had a geometric surface area of 1 cm². The capacitive properties of electrodes were determined by cyclic voltammetry (CV), galvanostatic charge–discharge and electrochemical impedance spectroscopy (EIS) measurements. All of electrochemical measurements were carried out on an electrochemical working station (CHI660E, Shanghai Chenhua, China) at room temperature with 2 M KOH as the electrolyte. The cyclic stability of NiWO₄–CoWO₄ positive electrode and hybrid supercapacitor were also evaluated by electrochemical working station within the voltage range of 0–0.4 V and 0–1.6 V, respectively.

3 Results and discussion

3.1 Characterizations of NiWO₄, CoWO₄ and NiWO₄–CoWO₄ nanocomposites

NiWO₄, CoWO₄ and NiWO₄–CoWO₄ nanocomposites were prepared by a simple chemical co–precipitation method through the reaction between Na₂WO₄·2H₂O and NiCl₂·6H₂O/CoCl₂·6H₂O in a molar ratio of 1:1. The reactions can be expressed as [36, 37]:

Because the sodium chloride byproduct can be easily removed by washing, the precipitate is the pure NiWO₄–CoWO₄ nanocomposite.

Fig. 1 shows the XRD patterns of the as–prepared samples which consist of broad diffraction peaks with low intensity, indicating the poorly crystalline and amorphous characteristic of the products, and this is consistent with previous results on NiWO₄ and CoWO₄ [25, 27]. **Fig. 2** plots XPS spectra of the as–prepared amorphous samples. The typical Ni (2p, 3p, 3s), W (4p, 4d, 4f),

Co2p and O1s signals are observed in the full spectrum for all the nanocomposite. A careful exam of the high-resolution Ni2p_{3/2} peak at 856.3 eV and Co2p_{3/2} spectrum at 781.5 eV indicates Ni and Co present in the divalent state (**Fig. 2b, 2d**) [38, 39]. Combined with the reaction mechanism, XRD and XPS results, we confirmed the successful formation of amorphous NiWO₄-CoWO₄ nanocomposite.

Fig. 3 shows the FESEM and TEM images of as-prepared samples. As observed from FESEM images (**Fig. 3 a-c**), the as-prepared samples show a cauliflower-like morphology randomly assembled by dozens of tiny individual nanoparticles with abundant mesoporous. TEM images show that individual NiWO₄ and CoWO₄ nanoparticles are self-assembled and aggregated together to form NiWO₄-CoWO₄ nanocomposite. In specific, the CoWO₄ nanoparticles were firstly obtained by chemical co-precipitation method, and form small clusters of nanoparticles in the solution. Then, the Ni²⁺ was added dropwise and reacted with the excess WO₄²⁻, and attached on the surface of CoWO₄ to form NiWO₄-CoWO₄ nanocomposite. As the particle size is extremely small, thus will significantly shortening the path length of ion transfer and drastically enhancing the charge-discharge rate [40].

N₂ adsorption-desorption experiments were performed to examine the pore characteristics of the as-prepared samples (**Fig. 4**). The NiWO₄, CoWO₄ and NiWO₄-CoWO₄ nanocomposite show a typical type-IV isotherm profile with distinct hysteresis loops. The Brunauer-Emmett-Teller (BET) specific surface area for NiWO₄, CoWO₄ and NiWO₄-CoWO₄ materials are 28.2, 99.5, 150.7 m² g⁻¹, with the total pore volume of 0.13, 0.13, 0.2 cm³ g⁻¹, respectively. It is worthy noted that the specific surface area of CoWO₄ is significantly higher than NiWO₄ owing to the small grain size of CoWO₄ (**Fig. 3**). Therefore, the nanocomposites will have more voids than individual

NiWO₄ and CoWO₄, which contributes to the large surface area and enhanced electrochemical properties of NiWO₄-CoWO₄ nanocomposites. Meanwhile, the Barrett-Joyner-Halenda (BJH) pore-size distribution centered at about 3.5 nm in diameter, implying that all the nanocomposites are mesoporous structure. Compared to pure NiWO₄ and CoWO₄ materials, 8NiWO₄-2CoWO₄ nanocomposites have higher specific surface areas, larger total pore volume and broad pore size distribution, which can facilitate the charge accumulation, ion transfer and penetration across the electrode/electrolyte interfacial area, resulting in the enhanced specific capacity and rate capability [41].

3.2 Effects of Co/Ni molar ratio on the faradaic performance of NiWO₄-CoWO₄

To further optimize the electrochemical properties of mesoporous NiWO₄-CoWO₄ nanocomposites, a series of samples with different Co/Ni molar ratios were synthesized and tested in a three-electrode system using 2 M KOH as electrolyte. **Fig. 5a** displays the CV curves of NiWO₄, CoWO₄ and NiWO₄-CoWO₄ nanocomposites at a scan rate of 20 mV s⁻¹. All the curves show a pair of redox peaks, indicating that the measured capacity is mainly governed by Faradaic redox mechanism, which is attributed to the reversible reactions between Ni²⁺/Ni³⁺ and Co²⁺/Co³⁺: [25]

Furthermore, the symmetric characteristic of the anodic and cathodic peaks reveal the excellent reversibility of the electrode. By contrast, it is apparent that the nanocomposite with Co/Ni molar ratio of 2:8 exhibits the largest integral area, implying the higher electrochemical energy storage capacity.

Fig. 5b shown the galvanostatic charge–discharge profiles tested at 0.5 A g^{-1} within the potential range between 0 and 0.4 V. Consistent with the CV results, the nanocomposite with Co/Ni molar ratio of 2:8 exhibits the longest discharging time, and the specific capacity are calculated according to the equation (5):

$$Q = C \times \Delta V = I \times \Delta t / m \quad (5)$$

where $Q \text{ (C g}^{-1}\text{)}$ is the charge stored, $C \text{ (F g}^{-1}\text{)}$ is the specific capacity, $\Delta V \text{ (V)}$ represents the width of the voltage window, $I \text{ (A)}$ is the charge–discharge current, $\Delta t \text{ (s)}$ is the discharging time, and $m \text{ (mg)}$ is the mass of the active material within the electrode. The calculated specific capacity of NiWO_4 , CoWO_4 and $\text{NiWO}_4\text{–CoWO}_4$ nanocomposite at different current densities are shown in **Fig. 5c**. On the one hand, it is clearly seen that pure NiWO_4 have higher specific capacity than pure CoWO_4 . However, the specific capacity decreased significantly with the increasing of current density. By contrast, CoWO_4 has superior rate capacity although its specific capacity is lower than the former. On the other hand, the incorporation of CoWO_4 significantly enhances the rate capacity of $\text{NiWO}_4\text{–CoWO}_4$ nanocomposite electrode. Impressively, the nanocomposite with Co/Ni molar ratio of 2:8 delivers high specific capacity of 196.7, 186.4, 173.4, 157.6, 147.0, 138.4, 133.0 C g^{-1} at the current density of 0.5, 1, 2, 4, 6, 8, 10 A g^{-1} , respectively, suggesting that 68% of the initial capacity is still retained when the discharging rate increased 20 times. This rate capability is superior to most of the previously reported samples including NiO [42], Ni(OH)_2 [43], NiWO_4 [25], NiCo_2O_4 [44], $\alpha\text{–NiMoO}_4$ [45] and approaching to Co_3O_4 [46], CoWO_4 [27], etc. Therefore, the nanocomposite electrode exhibits both high specific capacity and good rate capability, which is in good accordance with our previous hypothesis. The high electrochemical performance is benefit from its unique structures and ingenious material design. Firstly, the

incorporation of CoWO_4 provides a good rate capability and enables facile charge transport, while maintaining the high specific capacity of NiWO_4 in the nanocomposite. Secondly, the high specific surface area and large total pore volume of nanocomposite benefits the charge accumulation, ion transfer rate and penetration of electrode/electrolyte interfacial area [47, 48]. Meanwhile, abundant pore structure also provides convenience for the diffusion of the electrolyte. Finally, the small particle size has significantly shortening the path length of ion transfer and drastically enhancing the charge–discharge rate [2, 40].

The Nyquist plot of NiWO_4 , CoWO_4 and $\text{NiWO}_4\text{--CoWO}_4$ electrode are displayed in **Fig. 5d**. The semicircle in the high–frequency range corresponds to the charge transfer resistance (R_{ct}), and a sloped line in the low–frequency region represents the mass transfer resistance. The internal resistance (R_b) got from the intercept of the plots on the real axis, which mainly includes ion impendence of electrolyte, intrinsic impendence of the electrode materials and contact resistance between active materials and current collectors. The small and similar semicircle diameter for all electrodes indicates a low charge transfer resistance (R_{ct}). The internal resistance (R_b) value for NiWO_4 , CoWO_4 and $\text{NiWO}_4\text{--CoWO}_4$ electrode is 0.54, 0.48 and 0.31 Ω , respectively. At the low–frequency region, the higher slope value indicates a decrease in diffusion resistance, which facilitates the transport of electrolyte ions due to their mesoporous structure. The slope value of nanocomposite electrode is within NiWO_4 and CoWO_4 , and more close to the curve of CoWO_4 , demonstrates that the $\text{NiWO}_4\text{--CoWO}_4$ has higher electrical conductivity and lower ion transfer resistance than pure NiWO_4 [49]. The good electronic and ionic conductivity obtained from Nyquist plots further explain the excellent rate performance of the $\text{NiWO}_4\text{--CoWO}_4$ nanocomposites. Based on the above analysis, the nanocomposite with Co/Ni molar ratio of 2:8

has the highest electrochemical properties, thus we selected it as the positive material for hybrid supercapacitor in the following study.

3.3 Electrochemical performance of the NiWO₄–CoWO₄//AC hybrid supercapacitor

Aqueous hybrid supercapacitor was assembled by using of NiWO₄–CoWO₄ and AC as positive and negative electrodes, respectively. As for a hybrid supercapacitor, the charge balance between two electrodes follows the relationship as follows [50]:

$$Q_+m_+ = Q_-m_- \quad (6)$$

Where Q (C g⁻¹) is the specific capacity, m (mg) is the mass of the electrode. According to the charge–discharge test, the specific capacity of NiWO₄–CoWO₄ and AC electrode are 186.4 and 262.2 C g⁻¹ at a discharge current of 1 A g⁻¹ (**Fig. 6**). Based on the above equation (6), the optimal mass ratio between the electrodes expected to be $m(\text{AC})/m(\text{NiWO}_4) = 0.7$ in the hybrid supercapacitor. Thus, in the present study, the weight of positive and negative electrode is 4.0 mg and 2.8 mg, respectively.

Fig. 7a shows the CV curves of NiWO₄–CoWO₄//AC hybrid supercapacitor in 2 M KOH aqueous solution at various scan rates between 0 and 1.6 V. The CV curves exhibited a larger current area with broader redox peak and excellent reversibility when the scan rate increased from 10 to 50 mV s⁻¹, indicating a typical capacitor behavior of NiWO₄–CoWO₄//AC. Galvanostatic charge–discharge curves of hybrid supercapacitor at different current densities are shown in **Fig. 7b**. The charge–discharge curve shows an isosceles triangle, demonstrating the excellent reversibility and good coulombic efficiency. The specific capacity calculated from the discharge time are 135.5, 128.2, 121.6, 112.8, 102.1, 96.0, 89.6 and 84.0 C g⁻¹ at current densities of 0.25, 0.5, 1, 2, 4, 6, 8 and 10 A g⁻¹, respectively. Cycling capability is one of the key requirements for

practical applications. The cycling stability of device is shown in **Fig. 7d**, and it clearly seen that the capacity of the full cell increased in the first 100 cycles, possibly due to the activation of electrode [20]. Afterwards, the cell performance showed a slow decay with further cycling. It is worth noting that the final capacity of hybrid supercapacitor is still higher than the initial value after a continuous cycling of 5000 times, demonstrating superior long-term electrochemical stability.

Fig 8 shows the Ragone plot of the NiWO₄-CoWO₄//AC based hybrid supercapacitor. The energy and power density are calculated based on the equations (7) and (8):

$$E = \int_0^Q \frac{Q}{C} dQ \quad (7)$$

$$P = E / \Delta t = \int_0^Q \frac{Q}{C} dQ / \Delta t \quad (8)$$

Where C (F g⁻¹) is specific capacity, Q (C g⁻¹) is the charge stored, E (Wh kg⁻¹) is energy density, P (W kg⁻¹) is power density, Δt (s) is discharge times. As shown in **Fig 8**, it can clearly seen that the NiWO₄-CoWO₄//AC hybrid supercapacitor exhibits higher energy density than the AC//AC symmetric supercapacitor, NiWO₄//AC (25.3 Wh kg⁻¹ at 400 W kg⁻¹) and CoWO₄//AC (12.0 Wh kg⁻¹ at 400 W kg⁻¹) hybrid supercapacitor. The assembled hybrid supercapacitor can deliver a high energy density of 30.1 Wh kg⁻¹ at a power density of 200 W kg⁻¹, and still retain 18.7 Wh kg⁻¹ at a power density of 8 KW kg⁻¹. These results show an improved energy density at high density compared with previously reported about NiWO₄//AC (15.1 Wh kg⁻¹ at 4.8 KW kg⁻¹) [25], AC//β-Ni(OH)₂/Ni-foam (10.5 Wh kg⁻¹ at 687.3 W kg⁻¹) [49], Ni-Co oxide//AC (7.4 Wh kg⁻¹ at 1.9 KW kg⁻¹) [51], NiCo₂O₄-rGO//AC (10.5 Wh kg⁻¹ at 12.99 KW kg⁻¹) [52], AC//K_{0.27}MnO₂·0.6H₂O (17.6 Wh kg⁻¹ at 2 KW kg⁻¹) [53], CNT@MnO₂//CNT@PPy (15.8 Wh

kg⁻¹ at 8 KW kg⁻¹) [54], VNF//PANF (26.7 Wh kg⁻¹ at 0.22 KW kg⁻¹) [55], Bi₂O₃//MnO₂ asymmetric device (9.1 Wh kg⁻¹ at 3.37 KW kg⁻¹) [56]. In addition, the assembled device can light a green light emitting-diode and power a commercial liquid crystal display with the “CJLU” pattern, thus demonstrating the great potential of NiWO₄-CoWO₄//AC hybrid supercapacitor as power supply components in hybrid vehicle systems.

4 Conclusions

In conclusion, mesoporous NiWO₄-CoWO₄ nanocomposite with amorphous structure was successfully synthesized by a chemical co-precipitation under mild conditions. By combining the high specific capacity of NiWO₄ and good rate capability of CoWO₄, the nanocomposite electrode exhibit superior pseudocapactive performance. In specific, the nanocomposite can exhibits a maximum specific capacity of 196.7 C g⁻¹ at 0.5 A g⁻¹ in a three-electrode system, and retains 68% of the initial capacity when the discharging rate increased for 20 times. The high electrochemical performance is attributed to the ingenious material design, porous structure, small particle size and high surface area of electrode. Then NiWO₄-CoWO₄//AC hybrid supercapacitor was assembled and it can deliver a high energy density of 30.1 Wh kg⁻¹ at a power density of 200 W kg⁻¹. Meanwhile, it also exhibits a superior long-term electrochemical stability after 5000 times cycling. Therefore, NiWO₄-CoWO₄//AC appears as a promising candidate for future energy storage applied in hybrid electric vehicles and electric vehicles. This design of composite materials opens up new strategies for synthesize promising electrode for supercapacitors and other energy storage devices.

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Figures

Fig. 1 XRD patterns of NiWO₄, CoWO₄ and NiWO₄-CoWO₄ nanocomposite.

Fig. 2 XPS survey spectrum (a), Ni2p (b), W4f (c) and Co2p (d) spectra of NiWO₄ and NiWO₄-CoWO₄ nanocomposite.

Fig. 3 FESEM images of NiWO₄ (a), CoWO₄ (b), NiWO₄-CoWO₄ (c), low-magnification (d), high-magnification (e) TEM images of NiWO₄-CoWO₄ nanocomposite.

Fig. 4 N₂ adsorption-desorption isotherms (a) and BJH adsorption pore size distribution (b) of NiWO₄, CoWO₄ and NiWO₄-CoWO₄ nanocomposite.

Fig. 5 CV curves at the scan rate of 20 mV s⁻¹(a), charge-discharge curves at the current density of 0.5 A g⁻¹ (b), specific capacity as a function of current densities (c), EIS plots (d) of NiWO₄, CoWO₄ and NiWO₄-CoWO₄ nanocomposites in 2 M KOH aqueous electrolyte.

Fig. 6 CV curves at different scan rates of NiWO₄-CoWO₄ (a) and AC (c), galvanostatic charge-discharge curves at different current densities of NiWO₄-CoWO₄ (b) and AC (d) performed in a three-electrode system with 2M KOH as electrolyte.

Fig. 7 CV curves measured at different scan rates (a), charge-discharge curves measured at different current densities (b), specific capacity as a function of current densities (c) and the cycle life (d) of NiWO₄-CoWO₄//AC hybrid supercapacitor in 2 M KOH electrolyte.

Fig. 8 Ragone plots of the as-assembled NiWO₄-CoWO₄//AC hybrid supercapacitor compared with others.

Fig. 1 XRD patterns of NiWO_4 , CoWO_4 and $\text{NiWO}_4\text{-CoWO}_4$ nanocomposite.

Fig. 2 XPS survey spectrum (a), $\text{Ni}2p$ (b), $\text{W}4f$ (c) and $\text{Co}2p$ (d) spectra of NiWO_4 and $\text{NiWO}_4\text{-CoWO}_4$ nanocomposite.

Fig. 3 FESEM images of NiWO_4 (a), CoWO_4 (b), $\text{NiWO}_4\text{-CoWO}_4$ (c), low-magnification (d), high-magnification (e) TEM images of $\text{NiWO}_4\text{-CoWO}_4$ nanocomposite.

Fig. 4 N_2 adsorption-desorption isotherms (a) and BJH adsorption pore size distribution (b) of $NiWO_4$, $CoWO_4$ and $NiWO_4-CoWO_4$ nanocomposite.

Fig. 5 CV curves at the scan rate of 20 mV s^{-1} (a), charge–discharge curves at the current density of 0.5 A g^{-1} (b), specific capacity as a function of current densities (c), EIS plots (d) of NiWO_4 , CoWO_4 and $\text{NiWO}_4\text{-CoWO}_4$ nanocomposites in 2 M KOH aqueous electrolyte.

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