

# HIGH-RATE SODIUM BATTERY AND PREPARATION METHOD THEREOF

## TECHNICAL FIELD

5   **[0001]**   The present application relates to the technical field of sodium-ion battery manufacturing, particularly to a high-rate sodium battery and a preparation method thereof.

## BACKGROUND ART

10   **[0002]**   With technological advancement, the demand for energy storage devices continues to increase, and high-rate lithium-ion batteries have become the preferred choice for small power and energy storage devices. However, in recent years, with the continuous rise in raw material costs for lithium-ion batteries, manufacturing costs of lithium-ion batteries have also increased significantly. Such high prices have made it difficult for most small and medium-sized enterprises to survive, leading many companies to shift their focus to the research of sodium-  
15   ion batteries, which offer better cost-effectiveness.

20   **[0003]**   The main costs of lithium-ion batteries lie in the main cathode materials and the copper foil used as the anode current collector. The lithium element is relatively scarce in nature, and rarity enhances value. Sodium ions and lithium ions belong to the same main group, and sodium-ion batteries operate on a similar principle to lithium-ion batteries, utilizing the intercalation and deintercalation of sodium ions between the cathode and anode for charge and discharge. Moreover, the production equipment for sodium-ion batteries is essentially the same as that for lithium-ion batteries, eliminating the need for equipment replacement. Therefore, it is highly necessary to develop high-rate sodium-ion batteries with comparable performance to replace lithium-ion batteries.

25

## SUMMARY

**[0004]** The purpose of the present application is to provide a high-rate sodium battery and a preparation method thereof in view of the deficiencies of current technology.

**[0005]** In a first aspect, the present application provides a high-rate sodium battery, adopting  
5 the following technical solution.

**[0006]** A high-rate sodium battery, including a positive electrode sheet, a negative electrode sheet, a separator, and an electrolyte; a composition of the positive electrode sheet, by mass percentage, includes: 75-80% of a NVPF@C-N composite material, 10% of a positive electrode binder prepared by mixing sodium carboxymethyl cellulose and sodium polyacrylate  
10 in a mass part ratio of 1: 1, and 10-15% of a conductive agent Super P; a composition of the negative electrode sheet, by mass percentage, includes: 70-75% of a Fe<sub>7</sub>S<sub>8</sub>@N-C nanorod composite material, 15-20% of the conductive agent Super P, and 10% of sodium hydroxymethyl cellulose; the separator is a glass fiber membrane.

**[0007]** By adopting the above technical solution, the high-rate sodium battery of the present  
15 application utilizes various materials and technologies to improve the performance of the battery. Positive electrode sheet: the positive electrode sheet is a major component of the battery, responsible for storing and releasing energy. The positive electrode sheet in the present application uses the NVPF@C-N composite material, improving electronic and ionic conductivity through surface nitrogen-doped and carbon coating, thereby enhancing the  
20 reversible capacity and rate performance of the battery. Additionally, the positive electrode sheet further includes the positive electrode binder and conductive agent Super P. The positive electrode binder is prepared by mixing sodium carboxymethyl cellulose and sodium polyacrylate, which helps to improve the structural stability and conductivity of the positive electrode sheet. Negative electrode sheet: the negative electrode sheet is another major  
25 component of the battery, participating in electrochemical reactions together with the positive

electrode sheet. The negative electrode sheet in the present application uses the  $\text{Fe}_7\text{S}_8@\text{N-C}$  nanorod composite material. Through the synergistic effect of  $\text{Fe}_7\text{S}_8$  nanorods and a nitrogen-doped carbon layer, the cycling stability and high-rate performance of the sodium battery are improved. Furthermore, the negative electrode sheet further contains the conductive agent Super P and sodium hydroxymethyl cellulose, which helps to improve the conductivity and structural stability of the negative electrode sheet. Separator: the separator is an essential component of the battery for isolating the positive electrode sheet and negative electrode sheet to prevent short circuits. The separator in the present application uses the glass fiber membrane, which has good mechanical strength and chemical stability and can effectively prevent short circuits between the positive and negative electrode sheets. Electrolyte: the electrolyte is another essential component of the battery, responsible for transporting ions between the positive and negative electrode sheets. The electrolyte in the present application uses a sodium-ion electrolyte, which helps to improve the ion transfer efficiency of the battery, thereby enhancing the rate performance of the battery.

**[0008]** Preferably, the  $\text{Fe}_7\text{S}_8@\text{N-C}$  nanorod composite material is prepared by a method including the following steps:

**[0009]** S21, preparation of ferric hydroxide: placing ferric chloride hexahydrate and cetyltrimethylammonium bromide in a reactor, adding deionized water, and stirring magnetically at room temperature for 30-60 minutes to obtain a solution A, then transferring the solution A to a polytetrafluoroethylene-lined reaction kettle, and reacting at  $75-80^\circ\text{C}$  for 12-16 hours; after the reaction kettle cools to room temperature, collecting a precipitate from a reaction product, alternately washing the precipitate with ethanol and deionized water by centrifugation three times, then vacuum-drying the precipitate in a vacuum drying oven at  $60^\circ\text{C}$  for 8-12 hours to obtain the ferric hydroxide;

**[0010]** S22, preparation of polydopamine-coated ferric hydroxide: placing the ferric

hydroxide in a reactor, and mixing the ferric hydroxide with a 0.05 mol/L Tris buffer solution added to the reactor, sonicating for 30-60 minutes to disperse the ferric hydroxide uniformly , then adding dopamine hydrochloride to the reactor, stirring at 30°C in an oil bath for 8-10 hours to obtain a reaction solution, filtering the reaction solution to obtain a solid product, washing and drying the solid product, and then vacuum-drying the solid product in a vacuum drying oven at 60°C for 6-8 hours to obtain the polydopamine-coated ferric hydroxide; and

**[0011]** S23, preparation of nitrogen-doped carbon-coated Fe<sub>7</sub>S<sub>8</sub> nanorod composite: mixing the polydopamine-coated ferric hydroxide and sublimed sulfur powder uniformly to obtain a mixture, transferring the mixture to a corundum quartz boat, performing high-temperature carbonization and sulfurization under an argon atmosphere to obtain a product, then naturally cooling the product to room temperature with the corundum quartz boat to obtain the nitrogen-doped carbon-coated Fe<sub>7</sub>S<sub>8</sub> nanorod composite material, labeled as the Fe<sub>7</sub>S<sub>8</sub>@N-C nanorod composite material.

**[0012]** By adopting the above technical solution, the ferric hydroxide can be prepared in the step S21. The purpose of the step S21 is to synthesize the ferric hydroxide, which serves as the precursor for the Fe<sub>7</sub>S<sub>8</sub>@N-C nanorod composite material. The morphology and purity of ferric hydroxide significantly influence the structure and properties of Fe<sub>7</sub>S<sub>8</sub> in subsequent steps. By using the ferric chloride hexahydrate and cetyltrimethylammonium bromide as raw materials and reacting at specific temperatures for a duration, the particle size and morphology of ferric hydroxide can be controlled, thereby obtaining a uniform Fe<sub>7</sub>S<sub>8</sub>@N-C nanorod composite material with excellent electrochemical properties in subsequent steps. The polydopamine-coated ferric hydroxide can be prepared in the step S22. Polydopamine is an organic compound with good adhesion and easy polymerization, capable of forming a uniform coating layer on the surface of the ferric hydroxide. This layer not only serves as a nitrogen source for subsequent nitrogen doping but also can be converted into a carbon material with good

conductivity during high-temperature carbonization, thereby enhancing the electronic conductivity of the composite material. The nitrogen-doped carbon-coated Fe<sub>7</sub>S<sub>8</sub> nanorod composite material can be prepared in the step S23. Through high-temperature carbonization and sulfurization, the polydopamine-coated ferric hydroxide is converted into the nitrogen-doped carbon-coated Fe<sub>7</sub>S<sub>8</sub> nanorod composite material. The high-temperature treatment converts polydopamine into a carbon material and allows sulfur to react with iron to form Fe<sub>7</sub>S<sub>8</sub> nanorods. There is a synergistic effect between the nitrogen-doped carbon layer and the Fe<sub>7</sub>S<sub>8</sub> nanorods. The nitrogen-doped carbon layer provides good electronic conductivity, while the Fe<sub>7</sub>S<sub>8</sub> nanorods offer high ion storage capacity. This structure enhances the high-rate performance and cycling stability of the sodium battery due to the efficient construction of electron and ion transport channels while maintaining structural stability.

**[0013]** Preferably, in the step S23, process conditions of the high-temperature carbonization and sulfurization include: heating to 150°C at a heating rate of 5°C/min and holding for 2 hours, then heating to 550-560°C at a heating rate of 5°C/min and holding for 3-3.5 hours.

**[0014]** Preferably, the NVPF@C-N composite material is prepared by a method including the following steps:

**[0015]** S71, dissolving 3 molar parts of NaF, 2 molar parts of NH<sub>4</sub>H<sub>2</sub>PO<sub>4</sub>, and 2 molar parts of NH<sub>4</sub>VO<sub>3</sub> in 100 molar parts of deionized water, then adding 0.15 molar parts of citric acid and 0.12 molar parts of urea, mixing and stirring uniformly to obtain a mixed solution;

**[0016]** S72, continuously stirring and reacting the mixed solution at 70°C for 0.5-0.8 hours, then transferring a resulting reaction mixture to a stainless steel high-pressure polytetrafluoroethylene -lined reaction kettle, heating the reaction kettle in an oven at 110-120°C for 7-8 hours to obtain a hydrothermal product, freezing the hydrothermal product at -20°C for 24 hours, then freeze-drying and grinding the hydrothermal product to obtain a reaction precursor powder; and

**[0017]** S73, heating the reaction precursor powder to 300°C at a heating rate of 5°C/min under an argon atmosphere and sintering for 3-4 hours, then heating the reaction precursor powder to 650°C at a heating rate of 5°C/min and sintering for 8-10 hours, naturally cooling to room temperature to obtain the nitrogen-doped carbon-coated  $\text{Na}_3\text{V}_2(\text{PO}_4)_2\text{F}_3$  composite material, labeled as the NVPF@C-N composite material.

**[0018]** By adopting the above technical solution, the precursor solution is prepared in the step S71. The purpose of the step S71 is to prepare the mixed solution containing NaF,  $\text{NH}_4\text{H}_2\text{PO}_4$ ,  $\text{NH}_4\text{VO}_3$ , citric acid, and urea. Citric acid serves as a chelating agent and a carbon source, which helps to form a homogeneous solution and control the uniform distribution of metal ions. Urea serves as a nitrogen source, providing necessary elements for nitrogen doping in the subsequent steps. By precisely controlling the ratios of the raw materials and the mixing process, the uniformity of the precursor solution can be ensured, which is crucial for controlling the morphology and particle size of a NVPF crystal in the subsequent hydrothermal reaction. Hydrothermal reaction and freeze-drying are performed in the step S72. Heating in the high-pressure reaction kettle at 110-120°C promotes the growth and morphology formation of the NVPF crystal. Freeze-drying preserves the structure of the hydrothermal product, preventing structural collapse caused by capillary forces during the drying process. Hydrothermal conditions (temperature and time) significantly affect the crystal structure and morphology of the product, while freeze-drying maintains these structural features, playing a key role in the final battery performance. Heat treatment and nitrogen-doped carbon coating are performed in the step S73. The heat treatment involves two-stage of temperature increase. First, pre-treatment at 300°C is performed to remove residual moisture and organics, and then high-temperature sintering at 650°C is performed to form the NVPF crystal. During this process, the nitrogen source generated from the decomposition of urea and the carbon source derived from the citric acid work together to form a nitrogen-doped carbon coating layer. The nitrogen-doped

carbon coating layer not only improves the electronic conductivity of the material but also enhances the structural stability of the material. This structural design enables the NVPF@C-N composite material to exhibit excellent electrochemical performance, including high reversible capacity and good cycling stability, in the high-rate sodium battery.

5    **[0019]** Preferably, a composition of the electrolyte, by mass percentage, includes: 15% of NaPF<sub>6</sub>, 81% of a solvent, and 4% of an additive.

10    **[0020]** Preferably, a composition of the solvent, by mass percentage, includes: 45% of ethylene carbonate, 8% of ethyl methyl carbonate, and 47% of diethyl carbonate; a composition of the additive, by mass percentage, includes: 25% of vinylene carbonate, 37.5% of propylene sulfite, 12.5% of 2-(thio)-2-imidazoline, 12.5% of sodium difluoro(oxalato)borate, and 12.5% of sodium difluorophosphate.

**[0021]** In a second aspect, the present application provides a method for preparing of the high-rate sodium battery.

**[0022]** In summary, the present application has the following beneficial effects.

15    **[0023]** 1. Improvement of the initial discharge capacity: by using the NVPF@C-N composite material as the positive electrode material, the surface nitrogen-doped carbon coating of the material enhances the electrode electronic conductivity and ion diffusion rate, thereby enabling a higher initial discharge capacity.

20    **[0024]** 2. Improvement of the initial coulombic efficiency: the initial coulombic efficiency is a ratio of the charge capacity to the discharge capacity of the battery in the initial charge-discharge cycle. The presence of nitrogen-doped carbon coating layer reduces the decomposition of the electrolyte and the irreversible loss of sodium ions, thereby improving the initial coulombic efficiency.

25    **[0025]** 3. Stable cycling performance: the specific structural design of the Fe<sub>7</sub>S<sub>8</sub>@N-C nanorod composite material, including synergistic effects of the Fe<sub>7</sub>S<sub>8</sub> nanorods and the

nitrogen-doped carbon layer, provides a stable electrochemical reaction platform, reduces the material degradation during cycling, and thus maintains the cycling stability of the battery.

**[0026]** 4. Excellent high-rate performance: the high-rate performance refers to the performance of the battery under high-rate charge-discharge conditions. The nitrogen-doped carbon coating layer and the nanorod structure in the present application facilitate rapid electron transport and ion diffusion, enabling the battery to maintain good performance even at high rates.

**[0027]** 5. Long service life: optimizing positive and negative electrode materials improves the chemical stability and mechanical strength of the materials, reducing active material loss and structural damage during long-term cycling, thereby extending the service life of the battery.

**[0028]** 6. Simple and mild preparation method: the preparation method of the present application is simple with mild reaction conditions, requiring no expensive equipment or harsh reaction conditions, reducing production costs, and suitable for large-scale production.

15

## **DETAILED DESCRIPTION**

**[0029]** The embodiments of the present application will be described in detail below with reference to examples.

**[0030]** Preparation Example 1: preparation of Fe<sub>7</sub>S<sub>8</sub>@N-C Nanorod composite material

**[0031]** The preparation method of the Fe<sub>7</sub>S<sub>8</sub>@N-C nanorod composite material included the following steps.

**[0032]** S21. Preparation of ferric hydroxide: 10.8 g of ferric chloride hexahydrate and 10 g of cetyltrimethylammonium bromide were placed in a reactor. 400 mL of deionized water was added, then stirred magnetically at room temperature for 30 minutes to obtain a solution A. The solution A was then transferred to a polytetrafluoroethylene(PTFE)-lined reaction kettle and

25

reacted at 75°C for 16 hours. After the reaction kettle was cooled to room temperature, a precipitate was collected and alternately washed with ethanol and deionized water by centrifugation three times, then the precipitate was vacuum-dried in a vacuum drying oven at 60°C for 8 hours to obtain the ferric hydroxide.

**[0033]** S22. Preparation of polydopamine-coated ferric hydroxide: 10 g of the ferric hydroxide was placed in a reactor, and the ferric hydroxide was mixed with 5 L of a 0.05 mol/L Tris buffer solution added to the reactor to obtain a mixture. The mixture was sonicated for 30 minutes to disperse the ferric hydroxide uniformly. Then, 4 g of dopamine hydrochloride was added to the reactor, and then stirred at 30°C in an oil bath for 8 hours to obtain a reaction solution. The reaction solution was filtered to obtain a solid product, and then the solid product was washed, dried, and vacuum-dried in a vacuum drying oven at 60°C for 6 hours to obtain the polydopamine-coated ferric hydroxide.

**[0034]** S23. Preparation of nitrogen-doped carbon-coated Fe<sub>7</sub>S<sub>8</sub> nanorod composite material: 10 g of the polydopamine-coated ferric hydroxide and 40 g of sublimed sulfur powder were mixed uniformly to obtain a mixture. The mixture was transferred to a corundum quartz boat and subjected to high-temperature carbonization and sulfurization under an argon atmosphere to obtain a product with the following conditions: heating to 150°C at a heating rate of 5°C/min and holding for 2 hours, then heating to 550°C at a heating rate of 5°C/min and holding for 3.5 hours. The product was naturally cooled to room temperature with the corundum quartz boat to obtain the nitrogen-doped carbon-coated Fe<sub>7</sub>S<sub>8</sub> nanorod composite material, labeled as the Fe<sub>7</sub>S<sub>8</sub>@N-C nanorod composite material.

**[0035]** Preparation Example 2: preparation of Fe<sub>7</sub>S<sub>8</sub>@N-C Nanorod composite material

**[0036]** The preparation method of the Fe<sub>7</sub>S<sub>8</sub>@N-C nanorod composite material included the following steps.

**[0037]** S21. Preparation of ferric hydroxide: 10.8 g of ferric chloride hexahydrate and 10 g

of cetyltrimethylammonium bromide were placed in a reactor. 400 mL of deionized water was added, then stirred magnetically at room temperature for 60 minutes to obtain a solution A. The solution A was then transferred to a PTFE-lined reaction kettle and reacted at 80°C for 12 hours. After the reaction kettle was cooled to room temperature, a precipitate was collected and alternately washed with ethanol and deionized water by centrifugation three time, then the precipitate was vacuum-dried in a vacuum drying oven at 60°C for 12 hours to obtain the ferric hydroxide.

**[0038]** S22. Preparation of polydopamine-coated ferric hydroxide: 10 g of the ferric hydroxide was placed in a reactor, and the ferric hydroxide was mixed with 5 L of a 0.05 mol/L Tris buffer solution added to the reactor to obtain a mixture. The mixture was sonicated for 60 minutes to disperse the ferric hydroxide uniformly. Then, 4 g of dopamine hydrochloride was added to the reactor, and then stirred at 30°C in an oil bath for 10 hours to obtain a reaction solution. The reaction solution was filtered to obtain a solid product, and then the solid product was washed, dried, and vacuum-dried in a vacuum drying oven at 60°C for 8 hours to obtain the polydopamine-coated ferric hydroxide.

**[0039]** S23. Preparation of nitrogen-doped carbon-coated Fe<sub>7</sub>S<sub>8</sub> nanorod composite material: 10 g of the polydopamine-coated ferric hydroxide and 40 g of sublimed sulfur powder were mixed uniformly to obtain a mixture. The mixture was transferred to a corundum quartz boat and subjected to high-temperature carbonization and sulfurization under an argon atmosphere to obtain a product with the following conditions: heating to 150°C at a heating rate of 5°C/min and holding for 2 hours, then heating to 560°C at a heating rate of 5°C/min and holding for 3 hours. The product was naturally cooled to room temperature with the corundum quartz boat to obtain the nitrogen-doped carbon-coated Fe<sub>7</sub>S<sub>8</sub> nanorod composite material, labeled as the Fe<sub>7</sub>S<sub>8</sub>@N-C nanorod composite material.

**[0040]** Preparation Example 3: preparation of Fe<sub>7</sub>S<sub>8</sub>@N-C Nanorod composite material

**[0041]** The preparation method of the Fe<sub>7</sub>S<sub>8</sub>@N-C nanorod composite material included the following steps.

**[0042]** S21. Preparation of ferric hydroxide: 10.8 g of ferric chloride hexahydrate and 10 g of cetyltrimethylammonium bromide were placed in a reactor. 400 mL of deionized water was added, then stirred magnetically at room temperature for 40 minutes to obtain a solution A. The solution A was then transferred to a PTFE-lined reaction kettle and reacted at 78°C for 14 hours. After the reaction kettle was cooled to room temperature, a precipitate was collected and alternately washed with ethanol and deionized water by centrifugation three times, then the precipitate was vacuum-dried in a vacuum drying oven at 60°C for 10 hours to obtain the ferric hydroxide.

**[0043]** S22. Preparation of polydopamine-coated ferric hydroxide: 10 g of the ferric hydroxide was placed in a reactor, and the ferric hydroxide was mixed with 5 L of a 0.05 mol/L Tris buffer solution added to the reactor to obtain a mixture. The mixture was sonicated for 45 minutes to disperse the ferric hydroxide uniformly. Then, 4 g of dopamine hydrochloride was added to the reactor, and then stirred at 30°C in an oil bath for 9 hours to obtain a reaction solution. The reaction solution was filtered to obtain a solid product, and then the solid product washed, dried, and vacuum-dried in a vacuum drying oven at 60°C for 7 hours to obtain the polydopamine-coated ferric hydroxide.

**[0044]** S23. Preparation of nitrogen-doped carbon-coated Fe<sub>7</sub>S<sub>8</sub> nanorod composite material: 10 g of the polydopamine-coated ferric hydroxide and 40 g of sublimed sulfur powder were mixed uniformly to obtain a mixture. The mixture was transferred to a corundum quartz boat and subjected to high-temperature carbonization and sulfurization under an argon atmosphere to obtain a product with the following conditions: heating to 150°C at a heating rate of 5°C/min and holding for 2 hours, then heating to 555°C at a heating rate of 5°C/min and holding for 3.3 hours. The product was naturally cooled to room temperature with the corundum quartz boat

to obtain the nitrogen-doped carbon-coated  $\text{Fe}_7\text{S}_8$  nanorod composite material, labeled as the  $\text{Fe}_7\text{S}_8@\text{N-C}$  nanorod composite material.

**[0045]** Preparation Example 4: Preparation of  $\text{NVPF}@\text{C-N}$  composite material

**[0046]** The preparation method of the  $\text{NVPF}@\text{C-N}$  composite material included the following steps.

**[0047]** S71. 3 mol of  $\text{NaF}$ , 2 mol of  $\text{NH}_4\text{H}_2\text{PO}_4$ , and 2 mol of  $\text{NH}_4\text{VO}_3$  were dissolved in 100 mol of deionized water. At the same, 0.15 mol of citric acid used as a chelating agent and a carbon source and 0.12 mol of urea used as a nitrogen source were added, mixed, and stirred uniformly to obtain a mixed solution.

**[0048]** S72. The mixed solution was continuously stirred and reacted at  $70^\circ\text{C}$  for 0.7 hours. A resulting reaction mixture was then transferred to a stainless steel high-pressure PTFE-lined reaction kettle. The reaction kettle was placed in an oven at  $115^\circ\text{C}$  and heated for 8 hours to obtain a hydrothermal product. The hydrothermal product was frozen at  $-20^\circ\text{C}$  for 24 hours, then freeze-dried, and ground to obtain a reaction precursor powder.

**[0049]** S73. The reaction precursor powder was heated to  $300^\circ\text{C}$  at a heating rate of  $5^\circ\text{C}/\text{min}$  under an argon atmosphere and sintered for 3.5 hours. Subsequently, the reaction precursor powder was heated to  $650^\circ\text{C}$  at a heating rate of  $5^\circ\text{C}/\text{min}$  and sintered for 9 hours. Then the reaction precursor powder was then naturally cooled to room temperature with a furnace to obtain the nitrogen-doped carbon-coated  $\text{Na}_3\text{V}_2(\text{PO}_4)_2\text{F}_3$  composite material, labeled as the  $\text{NVPF}@\text{C-N}$  composite material.

**[0050]** Preparation Comparative Example 1: Preparation of  $\text{NVPF}@\text{C}$  composite material

**[0051]** It was basically the same as Preparation Example 4, except that the addition amount of urea was 0.

**[0052]** Preparation Comparative Example 2: Preparation of  $\text{NVPF}$  material

**[0053]** It was basically the same as Preparation Example 4, except that the addition amounts

of both urea and citric acid were 0.

**[0054]** Preparation Comparative Example 3: Preparation of Fe<sub>7</sub>S<sub>8</sub> Nanorod material

**[0055]** The preparation method of the Fe<sub>7</sub>S<sub>8</sub> nanorod material included the following steps.

**[0056]** S21. Preparation of ferric hydroxide: 10.8 g of ferric chloride hexahydrate and 10 g

5 of cetyltrimethylammonium bromide were placed in a reactor. 400 mL of deionized water was added, then stirred magnetically at room temperature for 40 minutes to obtain a solution A. The solution A was then transferred to a PTFE-lined reaction kettle and reacted at 78°C for 14 hours. After the reaction kettle was cooled to room temperature, a precipitate was collected and alternately washed with ethanol and deionized water by centrifugation three times, then the  
10 precipitate was vacuum-dried in a vacuum drying oven at 60°C for 10 hours to obtain the ferric hydroxide.

**[0057]** S23. Preparation of Fe<sub>7</sub>S<sub>8</sub> nanorod composite: 10 g of the ferric hydroxide and 40 g of sublimed sulfur powder were mixed uniformly to obtain a mixture. The mixture was transferred to a corundum quartz boat and subjected to high-temperature carbonization and  
15 sulfurization under an argon atmosphere to obtain a product with the following conditions: heating to 150°C at a heating rate of 5°C/min and holding for 2 hours, then heating to 555°C at a heating rate of 5°C/min and holding for 3.3 hours. The product was naturally cooled to room temperature with the corundum quartz boat to obtain the Fe<sub>7</sub>S<sub>8</sub> nanorod material.

**[0058]** Example 1

20 **[0059]** A high-rate sodium battery, included a positive electrode sheet, a negative electrode sheet, a separator, and an electrolyte. A composition of the positive electrode sheet, by mass percentage, included 75% of the NVPF@C-N composite material prepared in the Preparation Example 4, 10% of a positive electrode binder prepared by mixing sodium carboxymethyl cellulose and sodium polyacrylate in a mass part ratio of 1:1, and 15% of a conductive agent  
25 Super P. A composition of the negative electrode sheet, by mass percentage, included 70% of

a Fe<sub>7</sub>S<sub>8</sub>@N-C nanorod composite material, 20% of the conductive agent Super P, and 10% of sodium hydroxymethyl cellulose. The separator was a glass fiber membrane. A composition of the electrolyte, by mass percentage, included 15% of NaPF<sub>6</sub>, 81% of a solvent, and 4% of an additive. A composition of the solvent, by mass percentage, included 45% of ethylene carbonate, 8% of ethyl methyl carbonate, and 47% of diethyl carbonate. A composition of the additive, by mass percentage, included 25% of vinylene carbonate, 37.5% of propylene sulfite, 12.5% of 2-(thio)-2-imidazoline, 12.5% of sodium difluoro(oxalato)borate, and 12.5% of sodium difluorophosphate. The Fe<sub>7</sub>S<sub>8</sub>@N-C nanorod composite material was prepared in Preparation Example 1.

10 **[0060]** The preparation method of the above high-rate sodium battery included the following steps.

**[0061]** S101, the NVPF@C-N composite material, positive electrode binder, and conductive agent Super P were mixed according to a corresponding ratio using a planetary mixer to obtain a positive electrode slurry.

15 **[0062]** S102, the Fe<sub>7</sub>S<sub>8</sub>@N-C nanorod composite material, conductive agent Super P, and sodium hydroxymethyl cellulose were mixed according to a corresponding ratio using a mixer to obtain a negative electrode slurry.

**[0063]** S103, the positive electrode slurry and the negative electrode slurry were coated using a coating machine according to a designed process standard requiring low-temperature coating to obtain a positive electrode coil and a negative electrode coil respectively, with a coating temperature of the positive electrode slurry being 135°C and a coating temperature of the negative electrode slurry being 110°C.

**[0064]** S104, the positive electrode coil and the negative electrode coil were subjected to vacuum baking, respectively, and baking conditions of the positive electrode coil were 100°C for 10 hours under a vacuum degree below -0.009 MPa, and baking conditions of the negative

25

electrode coil were 80°C for 6 hours under a vacuum degree below -0.009 MPa.

**[0065]** S105, the NaPF<sub>6</sub>, solvent, and additive were mixed according to a corresponding ratio to obtain the electrolyte.

**[0066]** S106, the high-rate sodium battery was manufactured through processes of rolling-electrode production-winding-assembly-baking-injection.

**[0067]** Example 2

**[0068]** A high-rate sodium battery, included a positive electrode sheet, a negative electrode sheet, a separator, and an electrolyte. A composition of the positive electrode sheet, by mass percentage, included 80% of the NVPF@C-N composite material prepared in the Preparation

Example 4, 10% of a positive electrode binder prepared by mixing sodium carboxymethyl cellulose and sodium polyacrylate in a mass part ratio of 1:1, and 10% of a conductive agent Super P. A composition of the negative electrode sheet, by mass percentage, included 75% of

a Fe<sub>7</sub>S<sub>8</sub>@N-C nanorod composite material, 15% of the conductive agent Super P, and 10% of sodium hydroxymethyl cellulose. The separator was a glass fiber membrane. A composition of

the electrolyte, by mass percentage, included 15% of NaPF<sub>6</sub>, 81% of a solvent, and 4% of an additive. A composition of the solvent, by mass percentage, included 45% of ethylene carbonate, 8% of ethyl methyl carbonate, and 47% of diethyl carbonate. A composition of the additive, by mass percentage, included 25% of vinylene carbonate, 37.5% of propylene sulfite,

12.5% of 2-(thio)-2-imidazoline, 12.5% of sodium difluoro(oxalato)borate, and 12.5% of sodium difluorophosphate. The Fe<sub>7</sub>S<sub>8</sub>@N-C nanorod composite materia was prepared in Preparation Example 2.

**[0069]** The preparation method of the above high-rate sodium battery included the following steps.

**[0070]** S101, the NVPF@C-N composite material, positive electrode binder, and conductive agent Super P were mixed according to a corresponding ratio using a planetary mixer to obtain

a positive electrode slurry.

**[0071]** S102, the  $\text{Fe}_7\text{S}_8@\text{N-C}$  nanorod composite material, conductive agent Super P, and sodium hydroxymethyl cellulose were mixed according to a corresponding ratio using a mixer to obtain a negative electrode slurry.

5 **[0072]** S103, the positive electrode slurry and the negative electrode slurry were coated using a coating machine according to a designed process standard requiring low-temperature coating to obtain a positive electrode coil and a negative electrode coil respectively, with a coating temperature of the positive electrode slurry being  $138^\circ\text{C}$  and a coating temperature of the negative electrode slurry being  $113^\circ\text{C}$ .

10 **[0073]** S104, the positive electrode coil and the negative electrode coil were subjected to vacuum baking, respectively, and baking conditions of the positive electrode coil were  $115^\circ\text{C}$  for 6 hours under a vacuum of  $-0.09\text{ MPa}$ , and baking conditions of the negative electrode coil were  $100^\circ\text{C}$  for 6 hours under a vacuum of  $-0.09\text{ MPa}$ .

**[0074]** S105, the  $\text{NaPF}_6$ , solvent, and additive were mixed according to a corresponding ratio  
15 to obtain the electrolyte.

**[0075]** S106, the high-rate sodium battery was manufactured through processes of rolling-electrode production-winding-assembly-baking-injection.

**[0076]** Example 3

**[0077]** A high-rate sodium battery, included a positive electrode sheet, a negative electrode  
20 sheet, a separator, and an electrolyte. A composition of the positive electrode sheet, by mass percentage, included 78% of the  $\text{NVPF}@\text{C-N}$  composite material prepared in the Preparation Example 4, 10% of a positive electrode binder prepared by mixing sodium carboxymethyl cellulose and sodium polyacrylate in a mass part ratio of 1:1, and 12% of a conductive agent Super P. A composition of the negative electrode sheet, by mass percentage, included 73% of  
25 a  $\text{Fe}_7\text{S}_8@\text{N-C}$  nanorod composite material, 17% of the conductive agent Super P, and 10% of

sodium hydroxymethyl cellulose. The separator was a glass fiber membrane. A composition of the electrolyte, by mass percentage, included 15% of NaPF<sub>6</sub>, 81% of a solvent, and 4% of an additive. A composition of the solvent, by mass percentage, included 45% of ethylene carbonate, 8% of ethyl methyl carbonate, and 47% of diethyl carbonate. A composition of the additive, by mass percentage, included 25% of vinylene carbonate, 37.5% of propylene sulfite, 12.5% of 2-(thio)-2-imidazoline, 12.5% of sodium difluoro(oxalato)borate, and 12.5% of sodium difluorophosphate. The Fe<sub>7</sub>S<sub>8</sub>@N-C nanorod composite material was prepared in Preparation Example 3.

**[0078]** The preparation method of the above high-rate sodium battery included the following steps.

**[0079]** S101, the NVPF@C-N composite material, positive electrode binder, and conductive agent Super P were mixed according to a corresponding ratio using a planetary mixer to obtain a positive electrode slurry.

**[0080]** S102, the Fe<sub>7</sub>S<sub>8</sub>@N-C nanorod composite material, conductive agent Super P, and sodium hydroxymethyl cellulose were mixed according to a corresponding ratio using a mixer to obtain a negative electrode slurry.

**[0081]** S103, the positive electrode slurry and the negative electrode slurry were coated using a coating machine according to a designed process standard requiring low-temperature coating to obtain a positive electrode coil and a negative electrode coil respectively, with a coating temperature of the positive electrode slurry being 135°C and a coating temperature of the negative electrode slurry being 110°C.

**[0082]** S104, the positive electrode coil and the negative electrode coil were subjected to vacuum baking, respectively, and baking conditions of the positive electrode coil were 110°C for 8 hours under a vacuum of -0.09 MPa, and baking conditions of the negative electrode coil were 90°C for 8 hours under a vacuum of -0.09 MPa.

**[0083]** S105, the NaPF<sub>6</sub>, solvent, and additive were mixed according to a corresponding ratio to obtain the electrolyte.

**[0084]** S106, the high-rate sodium battery was manufactured through processes of rolling-electrode production-winding-assembly-baking-injection.

5 **[0085]** Comparative Example 1

**[0086]** It was essentially the same as Example 3, except that an equal amount of NVPF@C composite prepared in Preparation Comparative Example 1 was used to replace NVPF@C-N composite.

**[0087]** Comparative Example 2

10 **[0088]** It was essentially the same as Example 3, except that an equal amount of the NVPF material prepared in Preparation Comparative Example 2 was used to replace the NVPF@C-N composite material.

**[0089]** Comparative Example 3

15 **[0090]** It was essentially the same as Example 3, except that an equal amount of the Fe<sub>7</sub>S<sub>8</sub> nanorod material prepared in Preparation Comparative Example 3 was used to replace the Fe<sub>7</sub>S<sub>8</sub>@N-C nanorod composite material.

**[0091]** Comparative Example 4

**[0092]** It was essentially the same as Example 3 except that an equal amount of diethylene glycol dimethyl ether containing 1 mol/L NaPF<sub>6</sub> was used to replace the electrolyte.

20 **[0093]** Performance testing

**[0094]** The high-rate sodium batteries prepared in Examples 1-3 and Comparative Examples 1-4 were sampled and placed for 24 hours, then subjected to constant-current charge/discharge testing using Land CT2001A from Wuhan Land Electronics Co., Ltd. The test results are shown in Table 1.

25 **[0095]** Capacity Testing: the discharge capacities at 1C and 10C rates were tested under a

voltage of 2-4V;

**[0096]** Cycle testing: the cyclic testing was performed under normal temperature and humidity conditions and a voltage of 2-4 V, with 1C rate charge/1C rate discharge and 1C rate charge/10C rate discharge cycles.

5 **[0097]** Table 1 Performance testing

| Item                                                       | Example 1 | Example 2 | Example 3 | Comparative Example 1 | Comparative Example 2 | Comparative Example 3 | Comparative Example 4 |
|------------------------------------------------------------|-----------|-----------|-----------|-----------------------|-----------------------|-----------------------|-----------------------|
| Initial discharge capacity at a rate of 1C(mAh/g)          | 121       | 125       | 123       | 105                   | 102                   | 118                   | 120                   |
| Initial discharge capacity at a rate of 10C (mAh/g)        | 110       | 114       | 112       | 81                    | 75                    | 87                    | 111                   |
| Initial discharge efficiency (%)                           | 93        | 95        | 95        | 97                    | 96                    | 97                    | 95                    |
| Capacity retention after 1000 cycles at a rate of 1C (%)   | 93        | 94        | 93        | 13                    | 38                    | 11                    | 89                    |
| Capacity retention after 1000 cycles at a rate of 10C (%)  | 89        | 90        | 89        | /                     | /                     | /                     | 84                    |
| Capacity retention after 10000 cycles at a rate of 1C (%)  | 65        | 66        | 65        | /                     | /                     | /                     | 56                    |
| Capacity retention after 10000 cycles at a rate of 10C (%) | 59        | 60        | 60        | /                     | /                     | /                     | 47                    |

**[0098]** The above examples are only used to explain and illustrate the technical solution of the present application, and not to limit it. Although the above examples provide specific explanations of the present application, related technical personnel should understand that modifications or equivalent substitutions can still be made to the specific embodiments of the present application, and any modifications and equivalent substitutions that do not depart from the spirit and scope of the present application should be included in the scope of the present application.

## WHAT IS CLAIMED IS:

1. A high-rate sodium battery, characterized by comprising a positive electrode sheet, a negative electrode sheet, a separator, and an electrolyte; wherein a composition of the positive electrode sheet, by mass percentage, comprises: 75-80% of a NVPF@C-N composite material,  
5 10% of a positive electrode binder prepared by mixing sodium carboxymethyl cellulose and sodium polyacrylate in a mass part ratio of 1: 1, and 10-15% of a conductive agent Super P; a composition of the negative electrode sheet, by mass percentage, comprises: 70-75% of a  $\text{Fe}_7\text{S}_8$ @N-C nanorod composite material, 15-20% of the conductive agent Super P, and 10% of sodium hydroxymethyl cellulose; the separator is a glass fiber membrane; the NVPF@C-N  
10 composite material is a nitrogen-doped carbon-coated  $\text{Na}_3\text{V}_2(\text{PO}_4)_2\text{F}_3$  composite material; the  $\text{Fe}_7\text{S}_8$ @N-C nanorod composite material is a nitrogen-doped carbon-coated  $\text{Fe}_7\text{S}_8$  nanorod composite material.

2. The high-rate sodium battery according to claim 1, characterized in that, the  $\text{Fe}_7\text{S}_8$ @N-C nanorod composite material is prepared by a method comprising the following steps:

15 S21, preparation of ferric hydroxide: placing ferric chloride hexahydrate and cetyltrimethylammonium bromide in a reactor, adding deionized water, and stirring magnetically at room temperature for 30-60 minutes to obtain a solution A, then transferring the solution A to a polytetrafluoroethylene-lined reaction kettle, and reacting at 75-80°C for 12-16 hours; after the reaction kettle cools to room temperature, collecting a precipitate from a  
20 reaction product, alternately washing the precipitate with ethanol and deionized water by centrifugation three times, then vacuum-drying the precipitate in a vacuum drying oven at 60°C for 8-12 hours to obtain the ferric hydroxide;

S22, preparation of polydopamine-coated ferric hydroxide: placing the ferric hydroxide in a reactor, and mixing the ferric hydroxide with a 0.05 mol/L Tris buffer solution added to  
25 the reactor, sonicating for 30-60 minutes to disperse the ferric hydroxide uniformly, then adding

dopamine hydrochloride to the reactor, stirring at 30°C in an oil bath for 8-10 hours to obtain a reaction solution, filtering the reaction solution to obtain a solid product, washing and drying the solid product, and then vacuum-drying the solid product in a vacuum drying oven at 60°C for 6-8 hours to obtain the polydopamine-coated ferric hydroxide; and

5        S23, preparation of nitrogen-doped carbon-coated Fe<sub>7</sub>S<sub>8</sub> nanorod composite material: mixing the polydopamine-coated ferric hydroxide and sublimed sulfur powder uniformly to obtain a mixture, transferring the mixture to a corundum quartz boat, then performing high-temperature carbonization and sulfurization under an argon atmosphere to obtain a product, then naturally cooling the product to room temperature with the corundum quartz boat to obtain  
10    the nitrogen-doped carbon-coated Fe<sub>7</sub>S<sub>8</sub> nanorod composite material, labeled as the Fe<sub>7</sub>S<sub>8</sub>@N-C nanorod composite material.

3. The high-rate sodium battery according to claim 2, characterized in that, in the step S21, a ratio of the ferric chloride hexahydrate, cetyltrimethylammonium bromide, and deionized water is 1.08 g: 1 g: 40 mL.

15        4. The high-rate sodium battery according to claim 2, characterized in that, in the step S22, a ratio of the ferric hydroxide, Tris buffer solution, and dopamine hydrochloride is 1 g: 500 mL: 0.4 g.

5. The high-rate sodium battery according to claim 2, characterized in that, in the step S23, a ratio of the polydopamine-coated ferric hydroxide to the sublimed sulfur powder is 1 g:  
20    4 g.

6. The high-rate sodium battery according to claim 2, characterized in that, in the step S23, process conditions of the high-temperature carbonization and sulfurization comprise: heating to 150°C at a heating rate of 5°C/min and holding for 2 hours, then heating to 550-560°C at a heating rate of 5°C/min and holding for 3-3.5 hours.

25        7. The high-rate sodium battery according to claim 1, characterized in that, the

NVPF@C-N composite material is prepared by a method comprising the following steps:

S71, dissolving 3 molar parts of NaF, 2 molar parts of  $\text{NH}_4\text{H}_2\text{PO}_4$ , and 2 molar parts of  $\text{NH}_4\text{VO}_3$  in 100 molar parts of deionized water, then adding 0.15 molar parts of citric acid and 0.12 molar parts of urea, mixing and stirring uniformly to obtain a mixed solution;

5 S72, continuously stirring and reacting the mixed solution at 70°C for 0.5-0.8 hours, then transferring a resulting reaction mixture to a stainless steel high-pressure polytetrafluoroethylene-lined reaction kettle, heating the reaction kettle in an oven at 110-120°C for 7-8 hours to obtain a hydrothermal product, freezing the hydrothermal product at -20°C for 24 hours, then freeze-drying and grinding the hydrothermal product to obtain a  
10 reaction precursor powder; and

S73, heating the reaction precursor powder to 300°C at a heating rate of 5°C/min under an argon atmosphere and sintering for 3-4 hours, then heating the reaction precursor powder to 650°C at a heating rate of 5°C/min and sintering for 8-10 hours, naturally cooling to room temperature to obtain the nitrogen-doped carbon-coated  $\text{Na}_3\text{V}_2(\text{PO}_4)_2\text{F}_3$  composite material,  
15 labeled as the NVPF@C-N composite material.

8. The high-rate sodium battery according to claim 1, characterized in that, a composition of the electrolyte, by mass percentage, comprises: 15% of  $\text{NaPF}_6$ , 81% of a solvent, and 4% of an additive.

9. The high-rate sodium battery according to claim 8, characterized in that, a composition  
20 of the solvent, by mass percentage, comprises: 45% of ethylene carbonate, 8% of ethyl methyl carbonate, and 47% of diethyl carbonate; a composition of the additive, by mass percentage, comprises: 25% of vinylene carbonate, 37.5% of propylene sulfite, 12.5% of 2-(thio)-2-imidazoline, 12.5% of sodium difluoro(oxalato)borate, and 12.5% of sodium difluorophosphate.

25 10. A method for preparing of the high-rate sodium battery according to any one of claims

1-9, characterized by comprising the following steps:

S101, mixing the NVPF@C-N composite material, positive electrode binder, and conductive agent Super P using a planetary mixer to obtain a positive electrode slurry;

5 S102, mixing the Fe<sub>7</sub>S<sub>8</sub>@N-C nanorod composite material, conductive agent Super P, and sodium hydroxymethyl cellulose using a mixer to obtain a negative electrode slurry;

S103, coating the positive electrode slurry and the negative electrode slurry using a coating machine according to a designed process standard to obtain a positive electrode coil and a negative electrode coil respectively, with a coating temperature of the positive electrode slurry below 140°C and a coating temperature of the negative electrode slurry below 115°C;

10 S104, performing vacuum baking on the positive electrode coil and the negative electrode coil separately; baking conditions of the positive electrode coil are 100-115°C for 6-10 hours under a vacuum degree below -0.085 MPa, and baking conditions of the negative electrode coil are 80-100°C for 6-10 hours under a vacuum degree below -0.085 MPa;

S105, mixing the NaPF<sub>6</sub>, solvent, and additive to obtain the electrolyte; and

15 S106, manufacturing the high-rate sodium battery through processes of rolling-electrode production-winding-assembly-baking-injection.