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Electrochemical Preparation of Nanoparticles of Nickel Hydroxide and Prediction of Its Capacity Properties

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Abstract—The results of the preparation of nanoparticles of nickel hydroxide by the electrochemical method using electrodes made of nickel foam are presented. A topology of H^+ migration routes in $Ni(OH)_2$ and NiOOH was determined by the methods of crystallochemical analysis. It was revealed that these compounds are two-dimensional ion conductors with high ionic mobility. It was shown that supercapacitors based on these compounds can possess a high rate of charge (discharge).

Keywords: nanostructured materials, nickel hydroxide nanoparticles, electrochemistry, supercapacitors

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INTRODUCTION

Nickel-containing or nickel nanostructured materials are widely applied in various industries, for example in catalytic or mechanical engineering [1–4], and are also used as additives in ceramics, magnetic fluids and conductive coatings, as well as for creating conductive pastes and the electrodes of supercapacitors [5–7].

The purpose of this work was to prepare the nickel hydroxide nanoparticles by the method of anode oxidation.

METHODS OF SYNTHESIS AND STUDY

Nanostructured nickel hydroxide powder was synthesized by the anode oxidation of nickel or foamed nickel in a two-electrode cell. We used two types of electrodes: metal nickel plates or nickel foam. In the first series of experiments, metal nickel plates (10 × 60 × 1 mm) served as the anode and cathode; the electrode spacing was 10 mm. In the second series, we used electrodes made of nickel foam (10 × 60 × 1 mm); the distance between them was 20 mm. The electrodes were immersed in a 100-mL electrochemical cell filled with distilled water (DE-25) or an electrolyte solution.

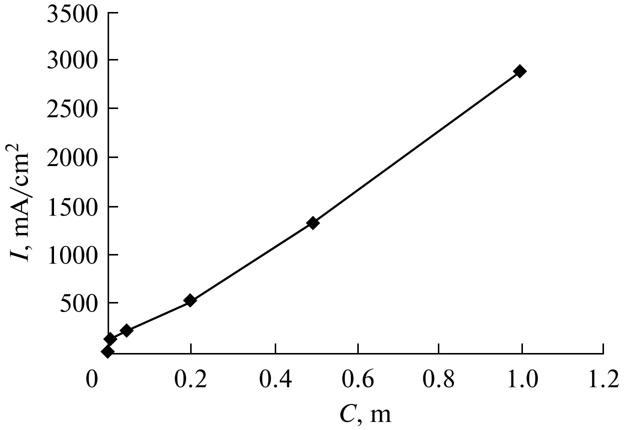

Fig. 1. Dependence of the current density on electrolyte (KOH) concentration.

Dependence of the size of nanoparticles synthesized by the electrochemical method on the type of electrode and electrolyte

Type of nickel electrodes	Electrolyte	$Ni(OH)_2$ nanoparticles size, nm	Ni nanoparticles size, nm
Metal nickel plates	Water	50	25
Metal nickel plates	KOH	50	30
Nickel foam	Water	35	30
Nickel foam	KOH	15	20

A series of experiments on anode oxidation was performed in the following modes: (1) electrodes of metal nickel in distilled water, voltage of 10–20 V (10–20 V/cm), the density of current 0.5–0.7 mA/cm^2, experiment duration 30–360 min; (2) electrodes of nickel foam in 0.05–1 M KOH solution, voltage of 10–20 V (5–10 V/cm), the density of current 100–3000 mA/cm^2, experiment duration 30–90 min.

The plates with the nickel hydroxide particles obtained were examined by the electron-probe X-ray diffraction analysis.

In order to determine the size of the nanoparticles in the resulting sols, we used transmission electron microscopy (EM-125) at an accelerating voltage $U_{\text{accel}} =$ 75 kV [8]. The X-ray phase studies were performed on a D8-Advance Bruker powder X-ray diffractometer (CuK_D-radiation) using the international database ICDD-2006. The average crystal size was determined by the Scherrer method.

EXPERIMENTAL

The effect of the electrolyte concentration on the current density is shown in Fig. 1. The current density increases with the increasing concentration of the electrolyte solution. As previously found, the particle sized decreases with an increase in the current density [9].

The separated particles were examined using the X-ray diffraction analysis. It was found that nickel hydroxide nanoparticles are of different sizes depending on the nature of the electrolyte (see table). The selection of electrodes also influences the size of the synthesized nanoparticles. The smallest particles were obtained when we used electrodes made of nickel foam and potassium hydroxide as an electrolyte. According to the X-ray phase diffraction analysis (Fig. 2), nanopowder formed on the electrode comprises two phases: a hexagonal $Ni(OH)_2$ phase (the particles are of a needle-shaped form with the maximum length of 15 nm and a diameter of 2–6 nm) and a cubic phase of metal nickel with the average particle size of 20 nm.

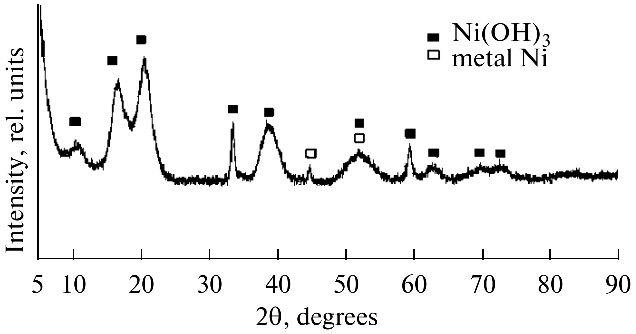

Fig. 2. X-Ray diffraction pattern of the powder obtained by the electrochemical method.

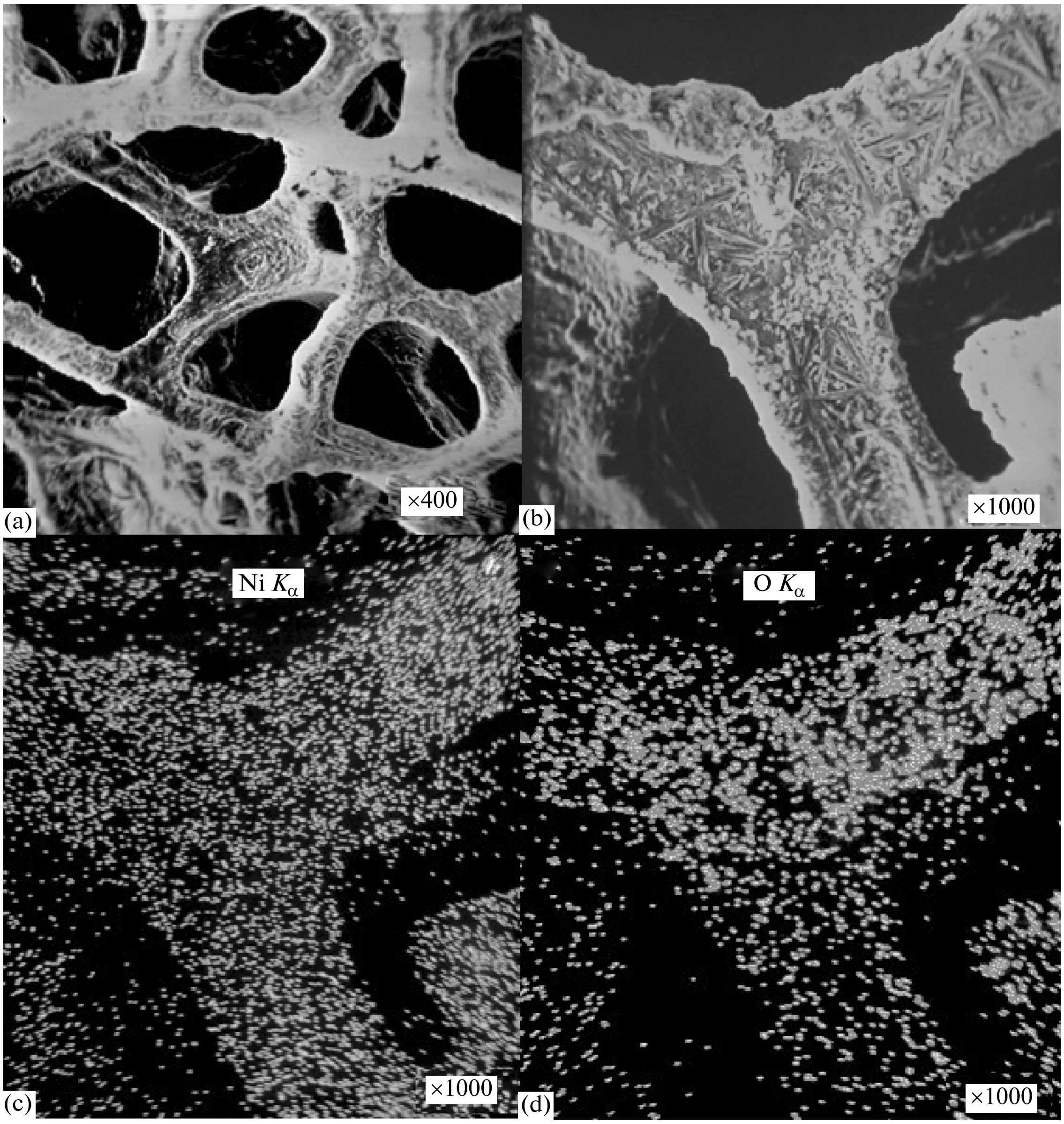

Fig. 3. Nickel foam: (a, b) nickel hydroxide particles in inverse electron beams; (c) in NiK_α X-rays; (d) in OK_α X-rays.

According to the data of X-ray microprobe spectral analysis conducted on a Camebax instrument, it was found that a uniform layer of nickel oxide or hydroxide compounds is formed (Fig. 3).

In order to obtain an oxide coating, the electrodes were calcined in air at 600°C.

The nickel foam–nickel oxide nanoparticles system can be used as a catalyst in the chemical reactions of various industrial processes, in particular in the carbonic conversion of methane [9].

Furthermore, it is noted that the following reaction takes place during operation of the electrochemical cell of a β-Ni(OH)$_2$-based supercapacitor:

$$\beta\text{-Ni(OH)}_2 \rightarrow \beta\text{-NiOOH} + \text{H}^+ + \text{e}^- \text{ [10].}$$

A topology of H^+ cation migration routes was built for the starting $Ni(OH)_2$ and NiOOH (Fig. 4) [11].

Figure 4 shows that these compounds are two-dimensional ion conductors. The topology of the migration channels of H^+ ions is built for the channel radius value of 0.85 Å and the spherical domain radius of 0.25 Å, which is more than sufficient for the H^+ diffusion. It follows that the supercapacitors based on these compounds will have a high rate of charge (discharge).

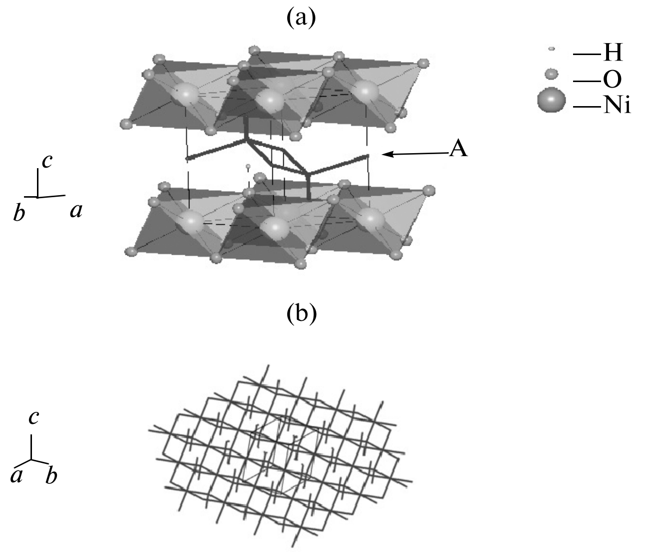

Fig. 4. Image of H^+ migration routes in NiOOH obtained by the crystallochemical analysis (a). The multiplied image of H^+ migration routes (b). A, H^+ migration routes.

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