Investigation of the deposition of metal nanoclusters on the surface of porous electrode materials by electrophoresis

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Abstract. The problems of coating on the entire surface of a highly porous electrode material based on activated carbon from a colloidal metal solution are considered. Experimental results demonstrated the possibility of metallization of porous carbon materials with nanoclusters of metals 2-10 nm in size by electrophoresis without reducing their initial porosity.

1. Introduction
The miniaturization of electronics has led to the fact that the main volume and weight of many devices is occupied by a power source, which is subject to ever-increasing demands on the duration of battery life, the amount of stored energy, the number of recharging cycles and the service life, which must be at least the lifetime of the electronic device itself. Thus, today there was a need for a sharp increase in the energy characteristics of current sources, which can be achieved by using microelectronic technologies and nanotechnologies in their production [1, 2].

Priority areas for improving miniature sources of electrical energy have become chemical sources of current, primarily lithium batteries and supercapacitor structures. Inferior to chemical sources of current in specific energy, supercapacitors considerably exceed them in terms of specific power and stability of charge-discharge characteristics over a wide temperature range.

Microelectronics manufacturing technologies has been studied a lot recently [13-15]. Microelectronic technologies and nanotechnologies are in demand for improving the parameters of electrode materials, as the main elements of chemical current sources and supercapacitor structures [3, 4].

Prospective electrode materials must meet several criteria: developed surface area, high electrical conductivity, availability of porous structure to wetting, chemical inertness to structural materials and so on. The most fully listed requirements are met by carbon materials of varying degrees of porosity [5-10]. One of the promising materials in this group are carbon cloths from activated carbon fibers – “busofit” (Figure. 1) [11].

The capacitance of the capacitor depends primarily on the surface area, which in carbon materials can increase in comparison with the geometric surface by $10^3-10^5$ times. In addition to a highly developed surface, electrode materials must have a low electrical resistance, both along the layer and across, as this determines the internal resistance of the source, which limits its output current. To reduce the electrical resistance of busofit and create an electrode material on its basis, two problems must be solved. First, apply a continuous layer of metal to the surface of the busofit, which will be a
current collector and reduce the internal resistance, which can be done using, for example, magnetron sputtering. Secondly, it is necessary to deposit a layer of metal on each filament of the busofit, which, on the one hand, will lower their electrical resistance, and on the other hand will increase the surface.

To solve this problem, it is proposed to use the technology of depositing nanoclusters of metals on the surface of porous materials by electrophoresis. As is known, nanometer-sized particles have a number of unique properties. They carry a positive charge, and their electrophysical and physicochemical properties are determined by the size of the nanoclusters. Therefore, the main task is to obtain metal particles with the desired size range and then position them in the porous space by electrophoresis. In this case, nanoparticles should have a uniform distribution over the surface.

![Initial busofit (a) and a snapshot with increasing (b)](image)

**Figure 1.** Initial busofit (a) and a snapshot with increasing (b)

2. Experimental

In the studies, the serial carbon cloth Busofit T-40 and similar carbon materials Busofit T-1, Busofit-T, Busofit-TM-4 were used. On the busofit threads, nanoclusters of nickel and silver were applied from the hydrosol. The preparation of metal nanoclusters was carried out by the method of electropulse dispersion due to an electric discharge between electrodes made of the metal immersed in distilled water [12]. The interelectrode distance was 100 μm, air gap of 1 mm, capacitor voltage up to 3 kV, capacitance of 1000 pF. Produced nanoclusters of metals are shown in Figure 2.

Under such a synthesis process, colloidal solutions of silver and nickel were obtained in which the initial sizes of the nanoclusters were 25-40 nm and 2-10 nm, respectively.

To metallize busofit with metal nanoclusters, an experimental laboratory reactor were developed using electrophoresis, its 3D model and a photograph of which is shown in Figure 3.

Busofit (3) was placed between the electrodes (2 and 5), after which the reactor was filled with a colloidal solution with silver or nickel nanoclusters and connected to an AC power source with a voltage of 40 V. Colloid particles have a charge, so they can move in an electric field. Reaching the destination electrode, the particles lose their charge and stick together - the colloidal solution coagulates on the surface of the material.
Figure 2. Produced silver nanoclusters of various sizes

Figure 3. 3D model (a) and photo of the laboratory reactor for the application of metal nanoclusters
(b) 1 - upper clamping cover, 2 - upper electrode, 3 - carbon cloth "busofit", 4 - base, 5 - lower electrode

Figure 4 shows shots of metallized busofit fibers obtained with an electron beam microscope. As can be seen, nickel is deposited on the busofit in a thin layer, and silver on the surface of the busofit fibers is formed in the form of large nanoparticles and crystallites, developing the surface of the fiber. The experiment of silver deposition on pre-nickel-plated busofit fibers also did not allow a single layer of silver to be deposited on the nickel sublayer as well as the initial busofit fibers. Apparently, this metallization result is associated with the initial size of metal nanoclusters, thin-film coatings are obtained from nanoclusters with sizes of 2-10 nm, and large nanoparticles and crystallites are formed from nanoclusters of a larger fraction.
3. Conclusions

It was shown the possibility of metallization of porous materials with metal nanoclusters by electrophoresis without reducing their initial porosity. This treatment allows the formation of a coating on the entire surface of a highly porous material, which reduces the electrical resistance and stabilizes the parameters of the electrode material.

To further study the metallization of highly porous materials, it is planned to use graduated colloidal solutions with a smaller spread of nanoclusters from various metals and alloys.

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