STABLE IONISTOR BATTERY FOR COMMUNICATION SYSTEMS

Study of technological possibilities of creating ionistor batteries to ensure the transceiver systems operation stability

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DOI: 10.36724/2664-066X-2020-6-4-11-17

ABSTRACT

The article describes a stable ionistor battery for infocommunication systems creating procedure. Based on a comparative analysis, the most balanced in terms of electrical characteristics, processability and availability components were selected. Using vacuum thermal resistive spraying, electrodes with a nanostructured carbon coating were manufactured. For this method, a structure with a high specific surface area obtaining technology has been formulated. Using two assembly methods, a cell of a stable ionistor battery has been built. It is possible to fully evaluate the physical and operational characteristics of the obtained ionistor batteries during long-term tests.

KEYWORDS: *ionistor, structured carbon coating, supercapacitor, thermal vacuum resistive spraying.*

INTRODUCTION

One of the reasons for the transmitting, receiving and information converting modules parasitic signals formation is supply circuits power fluctuations. The use of unstabilized power sources, pulse converters and power elements with a large spread of output parameters leads to the appearance of noise and errors in the information channels.

At the moment, there are two solutions for this problem - the use of stabilized sources powered by an external circuit, or the use of autonomous batteries [1, 2, 3]. The latter have several advantages – they are quite cheap, allows you to operate the equipment in hard-to-reach places and provide high power stability. But there are serious disadvantages, such as a limited service life and low environmental friendliness. Currently, electrochemical batteries are the most widely used. But a short service life (3-5 years), a small number of charge/discharge cycles, toxicity of components and severe requirements for operating conditions make them disadvantageous for most practical tasks.

As one of the alternative approaches to solve the tasks, caused by posed problems, is the energy storage devices new types creation [2, 4, 5]. In this paper, we examine the possibility of creating a storage device – an ionistor battery with nanostructured electrodes. The proposed design makes it possible to ensure power stability, a long service life and the ability to work in difficult climatic conditions with used the technologies high environmental safety.

STATEMENT OF THE PROBLEM AND THEORETICAL JUSTIFICATION OF THE STUDY

Table 1

A. Design rationale

Due to the of double electric layer (DEL) ionistor structure high performance characteristics [2, 4, 6], this technology is used to build an ionistor battery with nanostructured electrodes.

The simplest ionistor cell with a DEL construction is presented on the Fig. 1.

Fig. 1. Simple ionistor cell construction

A porous electrode paired with an electrolyte is involved in charge accumulation at the phase boundary. The current collector is necessary to ensure structures high charge-discharge currents. The separator electrically isolates the porous electrodes from each other while simultaneously providing high ionic conductivity for electrolyte ions.

B. Electrode material selection

Based on the chosen design, materials for the electrodes manufacturing were selected, which make an important contribution to the electric charge storage entire system efficiency [2, 6, 7]. Since the design of the electrodes can conditionally be classified as the active part (in which the charge accumulates directly) and the passive (current collector), then each of them has different requirements, and therefore the materials and manufacturing technology selection must satisfy different criteria.

The active part of the electrode is the most important and the most attention is paid to it. Analysis of existing active electrode layers materials (given in Table 1) showed that the best performance in combination with low cost are ensured when using carbon coatings. They have high conductivity and mechanical strength, a sufficient specific surface area and the technology does not require large expenditures in production.

Active electrode layers based on rare-earth materials and conductive polymers are in some cases more effective than carbon-based ones, but much more expensive or technologically less profitable.

In this work structured carbon materials were used as the main material component for electrode manufacturing, since they combine accessibility, environmental safety with high electronic conductivity (Table 2) [2, 6]. In addition, the proposed technology made it possible to achieve a high specific surface area, which critically affects the unit capacitance of the ionistor.

Supercapacitor (ionistor) electrode materials contrastive analysis

Electrode material		Operating voltage, V	Specific capacity, F/g
Carbon-base materials	Activated carbon	1,5	40
	Graphitic carbon	3,0	12
	Carbon aerogel	3,0	160
	Ctstructural carbon materials	1,5	140
	Mesoporous carbon	0,9	180
	Meso/macroporous carbon	0,8	130
	Single-walled carbon nanotube	2,3	50
	Multiwall carbon nanotube	2,5	13
Transient metal oxides	$\text{RuO}_2 \cdot \text{H}_2\text{O}$	1,0	650
	RuO_2 , on carbon	0,8	1000
	MnO_2	0,8	261
	MnO_2 , on activated carbon	2,2	29
	$\text{Ni}(\text{OH})_2$	0,8	578
	$\text{Ni}(\text{OH})_2$, on activated carbon	0,9	194
Conductive polymers	Poly (3-methylthiophene)	3,6	25
	Poly (3-methylthiophene), on MnO_2	1,0	381

Table 2

Carbon materials comparison

Material	Specific surface area	Conductance	The cost or synthesis complexity	Mechanical strength and stability	Remarks
Activated carbon	Very high	Very low	Very low	Very low	Requires conductive additive compounds, polymer binders, extrusion or casing to enhance some characteristics, often with damage to others
Colloidal carbon	Low	H		Low	More commonly used as an additive component
Disperse nanostructures (carbon nanotubes, fullerenes, etc.)	Medium	High	H	Low	Requires a similar approach as activated carbon, because of the high cost often used in small quantities as an additive component.
Carbon fabrics or array of carbon nanotubes	High	High	Very high	High	It is extremely expensive and difficult to achieve high reproducibility
Black lead powder	Medium	High	Low	Low	It has advantages and disadvantages specific to dispersed material, but particles have a high electrical conductivity/

Material	Specific surface area	Conductance	The cost or synthesis complexity	Mechanical strength and stability	Remarks
Structured carbon coating	Medium	High	Medium	High	Controlled morphology and structure
Carbon aerogel (black lead, graphene)	Very high	High	Very high	Very high	It was possible to obtain only in recent years, potentially extremely productive material

The structured carbon coating provides the best combination of characteristics, and further, the synthesis of this active electrode layer particular type is considered.

The second part of the electrode is the frame collector layer, sometimes called the current collector. The current collector material choice is given in the Table 3. The main criteria for this layer were: high electronic conductivity, mechanical stability, chemical inertness to the cell components, and availability.

Table 3

Current collector materials analysis

	Conductivity	Price	Processing ability	Chemical resistance
Aluminum		Low	High	Medium
Copper	y high	Medium	High	High
Precious metals (Ag, Au, Pt)	High or very high	High or very high	High or very high	Very high
Iron (steel)	Very low	Very low	Low	Low

All considered materials provide the necessary strength characteristics. Therefore, from Table 3 it follows that the most preferred materials for solving the task are aluminum and copper, as materials with the highest conductivity, availability and chemical resistance.

C. Electrolyte selection

To carry out the next step, an electrolyte for an ionistor cell capable of providing high charge-discharge currents was selected [2, 4, 9].

Existing electrolytes for super condenser with DEL comparative analysis is shown in the table below (Table 4).

Aqueous electrolytes have high ionic conductivity, are very available, and characterized by small ion sizes, which increases the electrolyte permeability into the pores of the active part of the electrode.

Aqueous electrolytes, in their turn, are also classified into several groups (Table 5).

Table 4

DEL super condensers electrolytes analysis

	Ion conductivity, S/cm	Voltage range, V	Accessibility	Ion sizes
Aqueous electrolyte	Up to 0,8	Up to 1,23	Very high	Small
Organic electrolyte	Approx. 0,02	Up to 5	Low	Large
Ionic liquids	Approx. 0,01	Up to 6	Low	Small

Table 5

Aqueous electrolytes classification

Salines	KNO ₃ , AlCl ₃
Strong acids	HClO ₄ , HClO ₃ , HNO ₃ , H ₂ SO ₄ , HCl, HI, HBr
Alkalis	NaOH, KOH, CsOH, RbOH, Sr(OH) ₂ , LiOH, Ba(OH) ₂ , Ca(OH) ₂

Basing on the information about conductivity (Table 6), availability and environmental friendliness, there were considered to use KOH-based electrolyte.

Table 6

Aqueous solutions peak molar mobility (S·m²·mol⁻¹) at 25 °C

Cation	$\lambda^{\infty} \cdot 10^4$ i	Anion	$\lambda^{\infty} \cdot 10^4$ i
H ⁺ , H ₃ O ⁺	349,8	1/2 Pb ²⁺	70
Li ⁺	38,7	1/2 Fe ²⁺	53,5
Na ⁺	50,8	1/3 Fe ³⁺	68
K ⁺	73,5	1/2 Ba ²⁺	63,6
Rb ⁺	77,8	1/2 Ca ²⁺	59,5
Cs ⁺	77,2	1/2 Sr ²⁺	59,5
Ag ⁺	61,9	1/2 Ba ²⁺	63,6
NH ₄ ⁺	73,6	1/2 Zn ²⁺	54
1/2 Cu ²⁺	56,6	1/2 Cd ²⁺	54
1/2 Mn ²⁺	53,5	1/3 Al ³⁺	63
1/2 Mg ²⁺	53,0	1/3 Pt ³⁺	69,8
OH ⁻	198,3	1/2 CrO ₄ ²⁻	85
F ⁻	55,4	1/2 C ₂ O ₄ ²⁻	74
Cl ⁻	76,35	1/2 SO ₄ ²⁻	80
Br ⁻	78,1	1/2 HPO ₄ ²⁻	57
I ⁻	76,8	1/3 H ₂ PO ₄ ⁻	12
HS ⁻	65	HC ⁻	54,6
NO ₃ ⁻	71,5	C ₂ H ₅ COO ⁻	35,8
HCO ₃ ⁻	44,5	CH ₃ COO ⁻	40,9
ClO ₄ ⁻	67,3	C ₆ H ₅ COO ⁻	32,3
1/2 CO ₃ ²⁻	69,3	1/4 [Fe(CN) ₆] ⁴⁻	110,5
1/2 SO ₄ ²⁻	79,8	1/3 [Fe(CN) ₆] ³⁻	100,9

The target electrolyte concentration was determined based on the dependence shown in Figure 2.

Fig. 2. Conductivity versus electrolyte concentration

Based on the graph, the highest conductivity of the KOH electrolyte is achieved at a concentration of 6 mol/L [10].

D. Separator material selection

The last element of the design is a separator – a porous material that provides electrolyte retention and opposite electrodes electrical insulation. Among the separation materials intended for electrochemical current sources, the main ones are the polypropylene, polyethylene, fiberglass, pulp and paper and fluoroplastic materials. It was found that the electrode material specific capacitance weakly depends on the nature of the separator. A weak correlation is also traced between the thickness of the separator and its impedance. Only porosity has a marked effect on impedance. Thus, the main criteria for the separator are high porosity and small thickness [11].

Based on the available commercial separator models, it was decided to use the YN-BS001 fiberglass separator (Fig. 3). Its thickness is about 300 microns, and porosity is not less than 85%.

Fig. 3. YN-BS001 separator

PRACTICAL ASPECTS OF CONSTRUCTION PROBLEM SOLUTION

The main task of the technological cycle of the work was the active layer of electrodes structured carbon coating formation. The considered methods for evolved carbon coatings producing have led to the conclusion about the promising possibilities of direct thermal vacuum resistive spraying [8]. This method allows obtaining both flat films and evolved crystallite-based structures depending on the spraying mode. For this reason, in further work this approach was chosen as the main one.

As the electrodes current collector frame layers, aluminum and copper foil with a thickness of 20 μm and a purity of no worse than 99.5% were used. Before applying the active layer, the surface of the foil was subjected to cleaning in a solution of ethanol ($\text{C}_2\text{H}_6\text{O}$, 95%) and drying in an oven for 15 minutes at a temperature of 85 $^{\circ}\text{C}$.

Substrates prepared in this way were placed in the working chamber of the Type Jee thermal vacuum-deposition system. This system implements two methods of thermoresistive spraying – indirect heating and direct evaporation of carbon material. The second method was used in the work to form a defined carbon structure.

Fig. 4. Vacuum Evaporator Type Jee thermal vacuum-deposition system

As the vaporized substance, graphite rods of 99.99% purity are used. They are sharpened in order to minimize the diameter of the mutual contact. The rods were placed in the chamber at a distance of 10-15 cm from the substrates (Figure 5).

Fig. 5. Preparation before spraying

Spraying was performed at a vacuum level of about 10-5 mm Hg. Before spraying, graphite rods were annealed with a closed shutter at a current value of 15A (900–950 °C) for 5 minutes. Temperature control was carried out using a remote infrared pyrometer.

The main spraying process was carried out in two stages - the carbon sublayer creation and the developed carbon surface formation. The sublayer was deposited for 90 minutes at a current of 15A (900–950 °C). This stage is necessary to ensure the required adhesion and passivation of the foil surface in order to minimize the electrolyte influence on it. The second stage of spraying was carried out at a current of 24 A for 180 minutes. The temperature of the rods reached 1500 °C. Thus, the total spraying time was 4 hours 30 minutes.

Fig. 6. Evaporation on the conducting foil process

OBTAINED SPRAYING RESULTS INVESTIGATION

To evaluate the presented technology recovery results, scanning electron microscopy with the elemental composition energy-dispersive analysis possibility were used. The study was carried out using a Carl Zeiss Auriga CrossBeam microscope.

At the first stage, the electrode main layer surface (current collectors based on aluminum and copper foil) was evaluated. Their surface before spraying can be estimated from the images in the Figure 7:

Fig. 7. Aluminium foil SEM images. Matte side exposure on the top, glossy on the bottom

Comparing the images, it can be seemed that the foil matte side has a more evolved and chaotic surface structure, which can affect the resulting coating characteristics.

Next, after carbon coating deposition, SEM images were obtained (Figure 8):

Fig. 8. SEM images of the matte (two on the top) and glossy (two on the bottom) side of an aluminum foil with a nanostructured carbon coating with magnification of 50 and 150 thousand times

The coating consists of submicron diameter crystal-like longitudinal structures. On the matte side formations are denser and larger. A more detailed inspection of the surface of the matte side is shown in the image below (Figure 9).

Fig. 9. Structured carbon coating increased 150 thousand times

The diameter of the structures at the baseline varies from 5 nm to 200 nm. The average particle diameter is 60 nm. The average distance between particles is 40 nm. The shape of the particles base varies from an irregular ellipse to a regular hexagon. It can be assumed that particles having the shape of a regular hexagon are a carbon single crystal with sp² bond hybridization. Due to the fact that the electron beam falls on the substrate at a slight deviation from the right angle, the dark background formation, indicating an elongated shape, can be seen.

For a more detailed study of the surface, it was carried out using an NT-MDT Nanoeducator II scanning probe microscope. The study confirmed that the structures are in the form of rods with a height of 200 nm to 850 nm.

A preliminary assessment of the resulting structure allows us to conclude that the surface development indicators, hence the specific surface area, are high. The latter is a key parameter that determines the ionistor cell final capacity

Electrolyte preparation

To prepare 25% KOH electrolyte, 100 ml of distilled water and 34 g of chemically pure KOH were used. To accelerate the alkali in water dissolution reaction passage, heating and mixing were carried out using a magnetic stirrer. Next, the solution was isolated from air and settled for 3-6 hours until completely clarified.

ASSEMBLY TECHNIQUE

At the final stage, stacking and coiling ionistor manufacturing technology assembly methods are considered. [2, 4] In simplest case, the cell is assembled as a hermetically

sealed package, with two manufactured electrodes embedded in it, between which there is a separator preventing electrical contact. The electrolyte is poured during the electrodes placement, or after sealing the packet with subsequent hole sealing. Electrical contacts may be formed from an ongoing electrode portion that is hermetically-sealed from the stack. Due to the fact that the electrodes are usually flat, this practically does not affect the tightness of the stack.

When using coiling manufacturing technology, at least four layers are used, two of which are “positive” and “negative” electrodes, and two others are separators. They are located alternating each other so that there is no electrical contact between the electrodes during winding. The current leads can be pre-attached to the current collector (preferably in several places, to reduce the equivalent series resistance), as shown in the design example (Figure 10).

Fig. 10. Ionistor battery construction example [12]

It is also possible to provide such arrangement of electrodes and separators that winding each end surface forms an electrical output of one of the electrodes. Refueling with electrolyte is carried out before winding or when placing the finished structure in a special case. The housing must be hermetically-sealed, durable and chemically inert to the supercapacitors internal environment. Each assembly method has its advantages and disadvantages. In the case of stacking technology, the required voltage inside one battery is easily achieved due to the cells series coupling. Coiling technology is preferable for production due to the ability to scale. Both methods were used in the work.

CONCLUSION

Within the framework of this study, the stabilized autonomous power source based on an ionistor battery creating possibility was considered. The main approaches to such energy storages design were considered. A complete technological study of all stages of finished cell item obtaining

is carried out. During experimental work steps, a proprietary approach to electrodes active part obtaining was proposed. All technological steps have been carried out to form the ionistor cell and its assembly elements. Performed operations allow us to conclude the possibility of such power sources cheap and maintainable production. However, a more detailed study of all operational properties is required.

Acknowledgments

The article authors are grateful to the “Prikladnyye Nanotekhnologii” (Applied Nanotechnology) core facilities center of Kazan National Research Technical University named after A.N. Tupolev for providing research technical opportunities.

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