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IMPROVEMENT OF THE THERMAL CHARACTERISTICS OF THE ELECTRIC HEATER IN THE ARCHITECTURE WITH ALUMINUM, NANOPOROUS ALUMINA AND RESISTIVE COMPONENT OF CARBON FIBER

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Abstract: The study presents the results from the investigations on electric characteristics and thermal field on the surface of the heater, based on anodic alumina with carbon fiber resistive element. It is shown that the application of heater made of aluminum, nanoporous alumina and carbon fiber allows decreasing the power consumption, providing the heating uniformity and, therefore, increasing their operating efficiency.

Keywords: heater, aluminum, nanoporous alumina, carbon fiber, thermal image.

1. Introduction

Year after year more and more heaters of different types come into use in the commercial and household devices. One of the mass-produced heaters is flat heater. Its usage allows promoting the opportunities for the creation of electrical devices of new types [1-4]. Its advantage can be explained by the more effective heat transfer of contact method comparing to the radiation one and other types of heat exchange [5].

The application of a metallic base with thin insulator layer in the design of heater enables creating the conditions for fast and uniform heat transfer to the heat receiver. The fast heat transfer from resistive element to the metallic base decreases the inertness of the heater and allows for the heater to reach the operating mode with minimum heat loss. Therefore, the investigation and development of the elements that can be quickly and uniformly heated in the entire surface are of great importance. The thermal characteristics of the flat heating elements, designed on the aluminum plates with a layer of nanoporous anodic alumina and resistive component of carbon fiber were explored in the present study.

2. Experimental

The samples of the flat heating elements with aluminum plates of 0.5 mm thickness are 60 × 24 mm in size. In order to form insulator layer the aluminum substrate was anodized in 0.3 M aqueous solution of oxalic acid at constant current density of 6 mA cm^{-2} for 40 min. This results in alumina layer of thickness 30 μm. Additionally, the porous alumina helped to solve a problem of adhesion of the prepreg layer to the aluminum surface. The surface morphology of the porous alumina films was studied by scanning electron microscopy (SEM) using DSM 982 (Zeiss) microscope. Then the SEM images were analyzed by ImageJ software. The porous alumina films had well-ordered porous structure with pore diameter of 38.6 nm (Fig. 1).

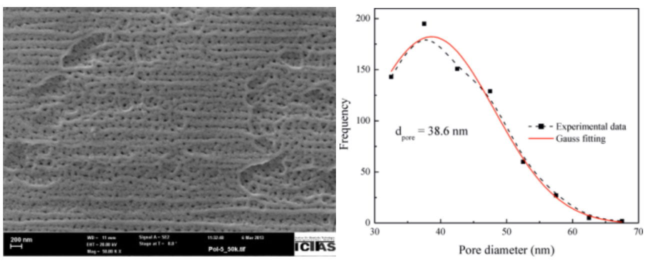

Figure 1. SEM image and results of analysis of nanoporous anodic alumina film on aluminum surface formed in oxalic acid

The design of the heater based on aluminum, nanoporous alumina and carbon fiber as a heating element is shown in Figure 2.

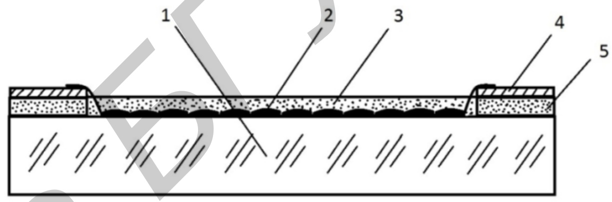

Figure 2. Design for flat heating element in the architecture with aluminum, nanoporous alumina, and resistive component of carbon fiber: *1* – aluminum with nanoporous alumina layer, *2* – resistive component by the carbon fiber string, *3*, *5* – prepreg, *4* – copper pad**.**

Before the thermal treatment the original reinforced prepreg layer was of 80 μm of thickness. In order to produce heating elements carbon fiber with liner dimensions of 80 μm (thickness) × 4 mm (wideness) × 170 mm (length) was used. The ends of the carbon fiber were covered with copper layer (thickness of 30 μm, plating) for further bending during heater assembly.

The heating element with carbon fiber possessed electric resistance of 60 Ω; power of 15 W (operating voltage 30 V). The resistance measurements of insulation were carried out by megaohmmeter F4101. The non-cooling thermal camera (FLIR T640) was used to study the heat field of the samples.

3. Results and discussion

According to the results of electric characteristic measurements of the heater elements the insulating resistance was not less than 10.0 GΩ at testing voltage of 500 V applied for 1 h.

The changes of operating characteristics of heaters based on anodic alumina were investigated in the course of long operating cycle. The operating voltage of 30 V was applied for 1 h then the power was switched off and the resistance was measured (Table). The measurements were repeated in an hour.

Table. Efficiency of flat heating elements in the architecture with aluminum, nanoporous alumina, and resistive component of carbon fiber during 2 h cycle (1 h input; 1 h output) at 30V

Heating element	***P*, W**	***t*, °C**	**Δ*t*, °C**	***R*, Ω**			**Δ*R*, Ω**
				before	**2 h**	**after**	
1	15.46	82	59	58.1	57.1	58.2	+0.1
2	15.71	82	59	56.6	56.1	56.6	0
3	15.52	81	58	57.8	57.3	57.9	+0.1
4	15.31	77	54	59.2	58.6	59.2	0

In order to evaluate the efficiency of flat heater based on the anodic alumina we compared the rate of temperature increase on the surface of the sampling heating element with the one on the surface of the heating element with glass-ceramic substrate having resistive nichrome layer. Images of flat heater that were used in experiments are shown in Fig. 3.

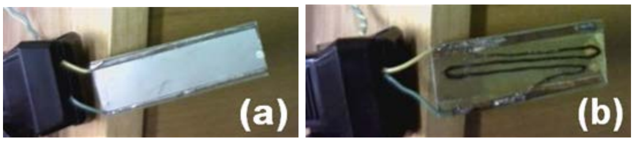

Figure 3. Heating element on glass-ceramic (*a*) and aluminum substrate with nanoporous alumina layer (*b*)

If the power is switched on the electrical energy is converted into thermal one; and the processes of heat transfer are initiated, i.e. the heat is transferred from heating surface to the heat-release one. When the voltage of 30 V is applied to the sampling heaters the thermal images on the surface with resistive element were registered by thermal camera after one and two minutes. The thermal images of the heaters designed on anodic alumina and glass-ceramic substrates during operation cycle are shown in Figure 4. The thermal field on the surface of the heater on anodic alumina was uniform both after one and two minutes of heating. On the contrary, in the thermal image of the heater on the glass-ceramic substrate with rectangular resistive element an area with increased temperature occurred in the centre. It should be noted that after 1 min and 2 min of heating the temperature on surface of the heater on the glass-ceramic substrate was by 35.5 and 40.7 ºC higher with respect to the one on the surface of heater on anodic alumina. The results obtained can be explained by considerably larger thermal conductivity of anodic alumina (210 W $m^{-1}K^{-1}$) compared to glass-ceramic (2.5 W $m^{-1}K^{-1}$).

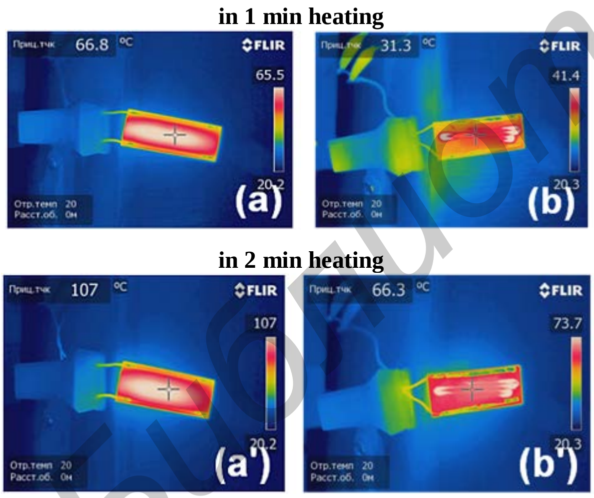

Figure 4. Thermal camera images of heating elements designed on glass-ceramic (*a* and *a'*) and aluminum substrate with nanoporous alumina layer (*b* and *b'*) in one and two minutes of heating.

The application of heater made of aluminum, nanoporous alumina and carbon fiber allows decreasing the power consumption, providing heating uniformity and, therefore, increasing their operating efficiency. It should be noted that the heaters on anodic alumina possess high mechanical strength, plain surface and minimal thickness, fast and uniform heating, vibration resistivity and environmental compatibility.

4. Conclusions

It was concluded that thermal field on the surface of the heater based on the anodic alumina with carbon fiber as resistive element was highly uniform. It was also shown that the application of heater made of aluminum, nanoporous alumina and carbon fiber allows decreasing the power consumption, providing heating uniformity and, therefore, increasing their operating efficiency.

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