Characteristics of flat electric aluminum heaters with nanoporous anodic alumina and a resistive element of carbon fiber

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Abstract

In the study the results of the investigations of heat efficiency of the heater based on anodic alumina with carbon fiber resistive element are presented. The experimental results showed that the utilization of electric aluminum heaters allows to reduce electric power consumption and provide for more efficient operation of flat electric heaters.

1 Introduction

More heaters of different types come into use in the commercial and household devices with each year. One of the mass-produced heaters is flat heater. Its usage allows promoting the opportunities for the creation of electrical devices of new types [1-3]. 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.

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 inertia 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 Results and discussion

2.1 Experimental part

The characteristics of flat electric aluminum heaters with carbon fiber as a resistive element were studied. Flat heater was in size of 60x24 mm. The thickness of the heater that consisted of aluminum base and aluminum cover was 0.5 mm.

The heating element consisted of copper conductors (pins) connected electrically with carbon fiber used for heating. The element was isolated from the surface of the aluminum base using a nanoporous anodic alumina layer. The thickness of the nanoporous anodic alumina formed by anodizing aluminum in a 0.4 M oxalic acid was about 40 microns.

The design of the heater based on aluminum, nanoporous alumina and carbon fiber as a heating element is shown in Figure 1.

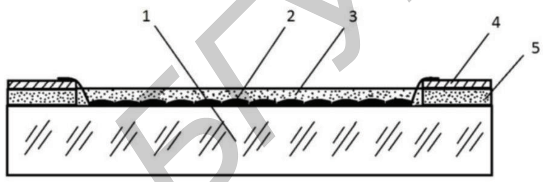

Figure 1 Design for flat heating element in the architecture with aluminum, nanoporous alumina, and resistive component of carbon fiber:
1 – aluminum with nanoporous alumina layer,
2 – resistive component by the carbon fiber string,
3, 5 – prepreg, 4 – copper pad.

The original reinforced prepreg layer was of 80 μm of thickness (before the thermal treatment). 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.

Two types of heaters were tested in our study, one with a resistance of 60 Ohms and another with 111 Ohms. Resistance measurements of insulation were carried out by megaohmmeter F4101. The non-cooling thermal camera (MobIR 4) was used for studies of the heat field of the samples and determining of the temperature of working surface.

2.2 Study of heat efficiency of aluminum heater

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.

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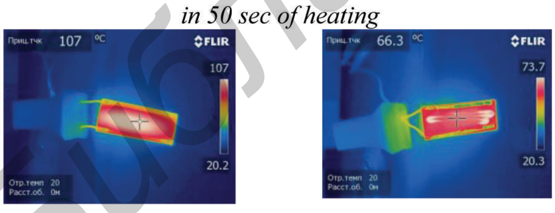
Table. Efficiency of flat heating elements in the architecture with aluminum, nanoporous alumina, and resistive component of carbon fiber during 2 h cycle (1 h input; 1 h output) at 30V

Heating element	*P*, W	*t*, ˚*C*	Δt, ˚C	*R, Ω* before	*R, Ω* 2 h	*R, Ω* after	ΔR, Ω
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 thin resistive nichrome layer.

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 50 sec (P=3.6W). The thermal images of the heaters designed on anodic alumina and glass-ceramic substrates during operation cycle are shown in Figure 2. The thermal field on the surface of the heater on anodic alumina was uniform after 50 sec 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 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 aluminum (210 W $m^{-1}K^{-1}$) compared to glass-ceramic (2.5 W $m^{-1}K^{-1}$).

in 50 sec of heating



a *b*

Figure 2 Thermal camera images of heating elements designed on glass-ceramic (a) and aluminum substrate with nanoporous alumina layer (b) in 50 sec of heating.

Hearting curves for electrical aluminum heaters for different resistance are shown in Figure 3.

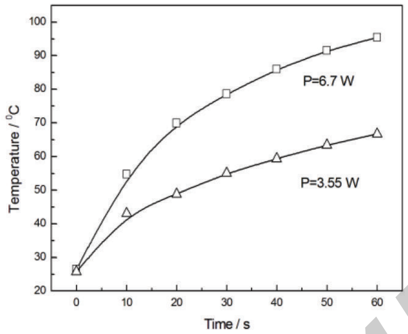


Figure 3 Heating curves for electric aluminum heaters with nanoporous anodic alumina and a resistive element of carbon fiber with a resistance of 60 Ohms (6.7 W) and 111 Ohms (3.55 W) at applied voltage of 19.8 V

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.

2.3 Conclusion

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.

2.4 References

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