Investigation of the Efficiency of the Heat Dissipation for the Heat-Conducting Circuit Boards Made of Aluminum with the Nanoporous Alumina Layer

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***Abstract**: The results of the investigation of the efficiency of the heat dissipation from the circuit board made of aluminum with the nanoporous alumina layer and conducting copper layer. In the construction of these circuit boards nanoporous alumina was used as insulator, which provided heat transfer from topology elements to the aluminum substrate. The conducting copper layer was formed by electroplating followed by chemical deposition of thin nickel layer. The diode MBRB16H60 was used as an element possessing high level of heat release. The temperature on the surface of the circuit board was measured by the thermocouple and the infrared images of the samples were studied by the thermal imaging camera. It was shown that proposed circuit boards allow significantly increasing the efficiency of the heat dissipation from the circuit board elements and reducing their operating temperature. The thermal conductivity of the nanoporous anodic alumina layer was determined to be 1.56 W K^{-1} m^{-1}.*

1. Introduction

In the modern production of electronics the number of components with high level of heat release is rapidly growing, e.g., circuit boards with powerful light-emitting diodes applied in illumination systems. The power of these diodes can vary from one to several dozen watts. Therefore, to maintain the optimal operating modes of the components with the high level of heat release, it is important to provide rapid heat dissipation from them. One of the ways of solving this problem is the application of aluminum as heat-conducting substrate [1–3].

The results of the investigation of the efficiency of the heat dissipation from the circuit board made of aluminum with the nanoporous alumina layer and conducting copper layer are presented. In the construction of these circuit boards nanoporous alumina was used as insulator, which provided heat transfer from topology elements to the aluminum substrate.

2. Experimental

To fabricate the circuit boards the plates of AA3003 alloys 1.5 mm in thick were used. The samples had a size 60 × 48 mm. First at the aluminum surface the layer of the naporous alumina 30 μm thick was formed by aluminum alloy anodizing in 0.4 M aqueous solution of oxalic acid at 40-60 V. Then at the surface of nanoporous alumina the nickel layer ca. 1 μm thick was chemically deposited. Hereafter the conducting copper layer 30 μm thick was obtained by electroplating. The pattern of copper conductors was formed by photolithography with further copper etching. The diode MBRB16H60 was used as an element possessing the high level of heat release. As a current source the current supply B5-78/1 was used. The temperature and heat distribution on the surface of the circuit board were measured by the thermocouple and thermal imaging camera (MobIR M4), respectively. The thermocouple was fixed by the heat conductive paste.

The effect of the current passed through the diode on the temperature on surface of the circuit board was studied. The efficiency of the heat dissipation by the circuit boards made of aluminum with nanoporous alumina layer was compared to the thermal characteristics of FR4 based circuit board (1.5 mm thickness) (Fig. 1).

a

b

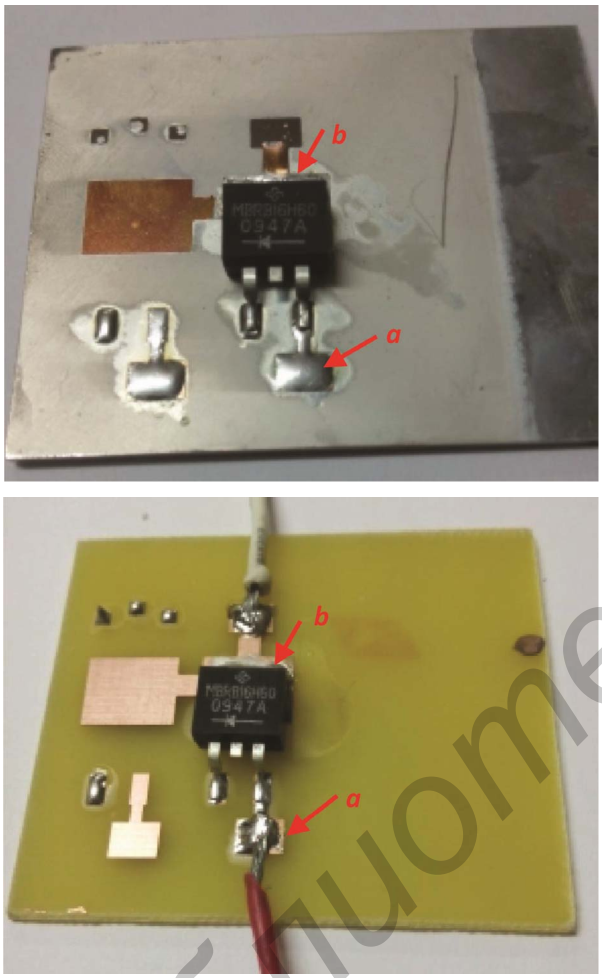


Fig. 1. The circuit boards with copper conductor and MBRB16H60 diode based on the a) aluminum with the nanoporous alumina layer and b) FR4.

a – the point at which the surface temperature of the board was measured; *b* – the point at which the temperature of the diode case was measured (the temperature of die)

In order to establish the heat properties of the aluminum board the surface of the board was heated by the carbon fiber. It allows achieving the homogeneous heating over the board surface in comparison to the lone diode. The reverse board side was kept constant by the aluminum radiator of large area.

In order to produce heating elements carbon fiber with liner dimensions 80 µm (thickness) × 4 mm (width) × 170 mm (length) was used. The ends of the carbon fiber were covered by 30 µm-thickness copper layer for further bending during heater assembly. Carbon fiber was fixed by 80 µm-thickness prepreg on the surface of nanoporius alumina. The heating element with carbon fiber possessed electric resistance 60 Ω [1].

3. Results and Discussion

3.1. The heat modes of the diode on the aluminum board and FR4

In 250 s of measurements the temperature of 3.4 W-diode die was 128 and 67 °C on FR4 and aluminum circuit board, respectively (Fig. 2). Thus, the temperature of die at the circuit board based on the aluminum with the layer of nanoporous alumina was shown to be 1.9 times lower than the one at the circuit board based on the FR4.

3.2. Heating of the aluminum board

Using of the diode as a heating source allowed showing the advantages of the circuit board on aluminum in comparison with the FR4 one. However, due to the small size of the diode the uneven heating of the circuit surface was observed, therefore, in order to estimate the thermal characteristics the carbon fiber heater was used.

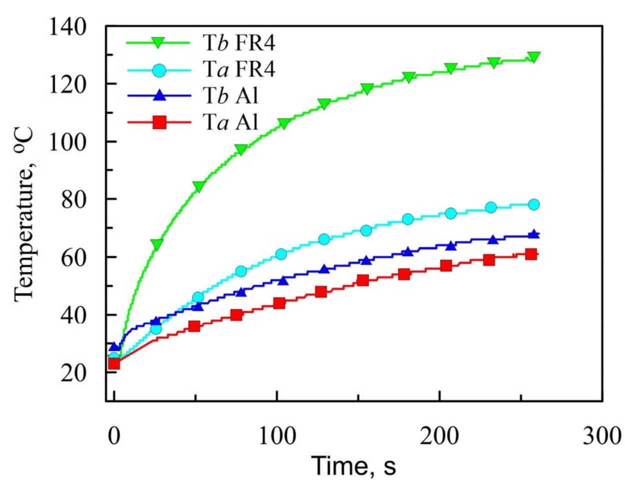


Fig. 2. The dependence of the diode die temperature at the points b (T_b) and a (T_a) on the heating time for circuit board on aluminum and FR4

a

b

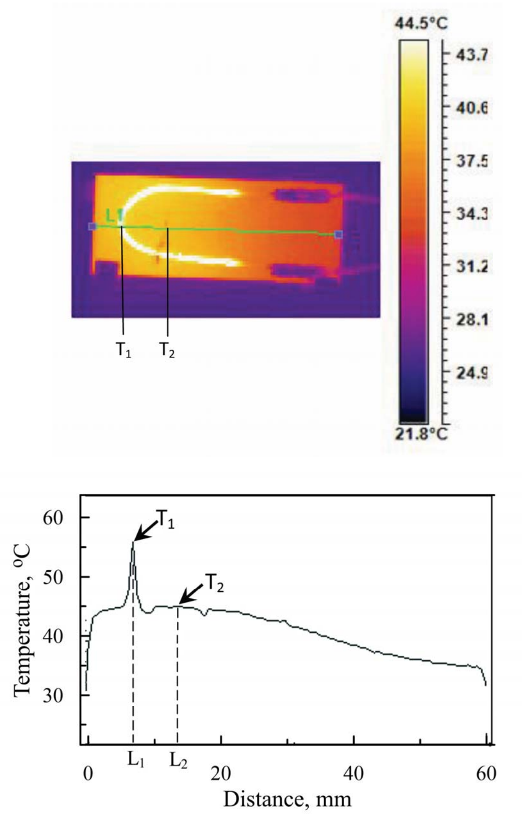


Fig. 3. The circuit board on aluminum with nanoporous alumina layer with carbon fiber heater in the thermal camera (a) and temperature distribution profile along the given line at the control points T_1 and T_2 measured in 25 s (b).

a

b

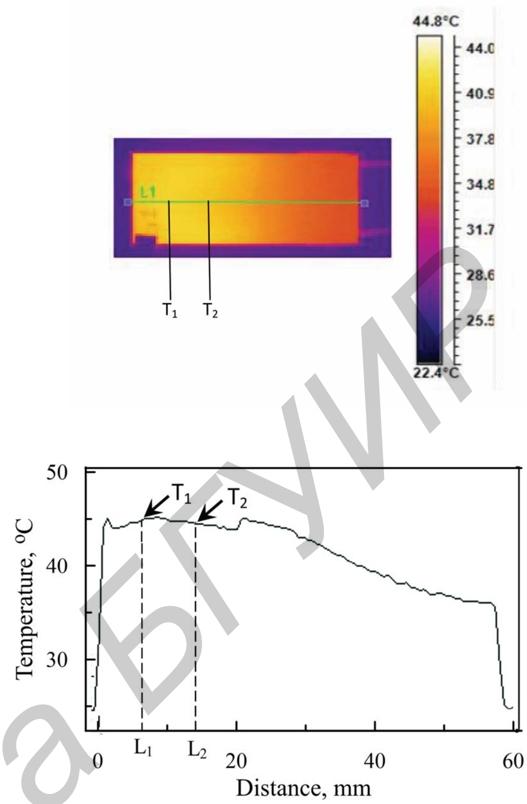


Fig. 4. The reverse side of the circuit board on aluminum with nanoporous alumina layer with carbon fiber heater in the thermal camera (a) and temperature distribution profile along the given line at the control points T_1 and T_2 measured in 25 s (b).

As can be seen from Fig. 3, the temperature distribution on the surface of aluminum circuit board is homogeneous, i.e. without local overheating. The temperature gradient of the heater relative to the surface of the circuit board is caused by the thermal conductivity of the nanoporous alumina. The analysis of the thermal fields from the reverse side of the circuit board on aluminum did not also show local overheating (Fig. 4).

It should be noted that the temperature on the surface of the reverse side of the circuit board on aluminum is approximately the same at the points located directly opposite (Fig. 5). The small diversion of the temperature on the front side of the circuit board in comparison to the reverse one can be explained by the presence of copper contact pad that has high conductivity. So, it can be seen that circuit board on aluminum with nanoporous alumina layer possesses high conductivity and generated heat reaches the reverse side of the circuit board very fast.

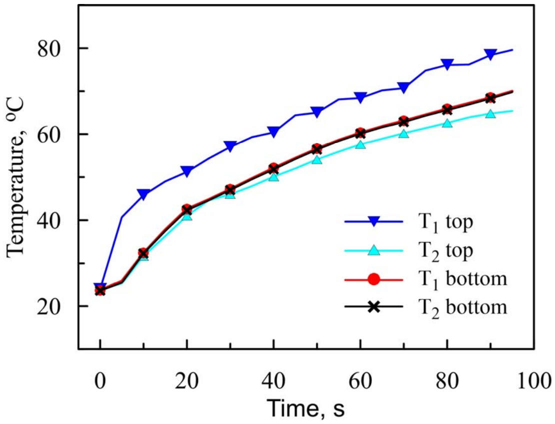


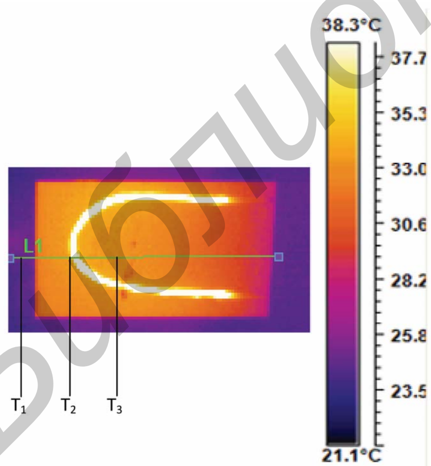
Fig. 5. The dependence of the temperature at the control points T_1 and T_2 on the heating time at the front side (See Fig. 3) and at the reverse side (See Fig. 4) for the circuit board on aluminum with nanoporous alumina layer.

3.3. The determination of the thermal parameters of the circuit board on aluminum with nanoporous alumina layer

As can be seen from Fig. 6, the thermal field is homogeneously disturbed over the surface of circuit board on aluminum with nanoporous alumina if the temperature of the reverse side of the circuit board was kept constant.

For the heating element power 3.4 W the temperature on the surface of the circuit board on aluminum reached 36.5 ºC in 25 s of heating and 48.1 ºC for carbon fiber in 40 s (Fig. 7).

a



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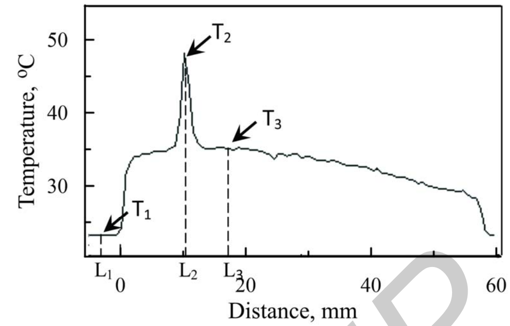

Fig. 6. The circuit board on aluminum with nanoporous alumina layer with carbon fiber heater in the thermal camera (a) and temperature distribution profile along the given line at the control points T_1 (the radiator surface), T_2 (carbon fiber) and T_3 (circuit board surface) measured in 25 s (b).

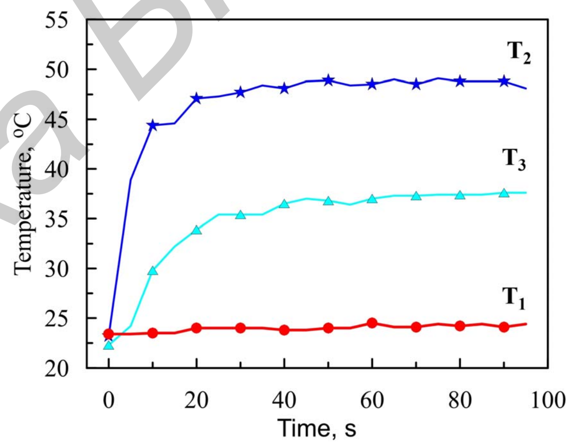

Fig. 7. The dependence of the temperature at the control points T_1, T_2 and T_3 on the heating time for the circuit board on aluminum with nanoporous alumina layer.

The results of the measurements of the changes in the temperature profile of the circuit board on aluminum at the interface with heating element allow calculating the thermal conductivity of the nanoporous alumina layer. This means that temperature profile has inflection points that correspond to the temperature on the surface of alumina layer at the interface with heater (T_1), the temperature of the alumina layer at the interface with aluminum (T_2) and equilibrium temperature of the aluminum (T_3) (Fig. 8).

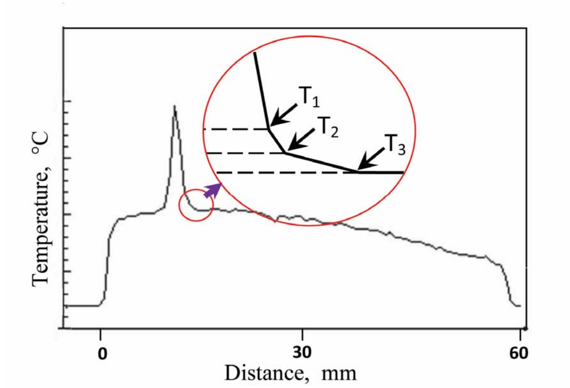

Fig. 8. The temperature distribution profile along the given line for the circuit board on aluminum. The insert shows the points which were chosen to determine the thermal conductivity of the nanoporous alumina: T_1 and T_2 are the temperatures of nanoporous alumina layer at the interface with heater and aluminum, respectively, T_3 is an equilibrium temperature of the aluminum layer.

In case when thermal flow passing through the nanoporous alumina layer and aluminum one is the same and cross section is S, the following equation can be written:

$$\lambda_{Al}\frac{(T_2 - T_3)}{d_{Al}}S = \lambda_{Al_2O_3}\frac{(T_1 - T_2)}{d_{Al_2O_3}}S \qquad (1)$$

from where we can obtain the thermal conductivity of nanoporous alumina:

$$\lambda_{Al_2O_3} = \lambda_{Al}\frac{d_{Al_2O_3}(T_2 - T_3)}{d_{Al}(T_1 - T_2)} \qquad (2)$$

where $\lambda_{Al_2O_3}$ is the thermal conductivity of nanoporous alumina; λ_{Al} is the thermal conductivity of aluminum layer; $d_{Al_2O_3}$ is the thickness of nanoporous alumina layer; d_{Al} is the thickness of aluminum layer; T_1 and T_2 are the temperatures of nanoporous alumina layer at the interface with heater and aluminum, respectively; T_3 is an equilibrium temperature of the aluminum layer.

As the result of the analysis of the temperature profile measured in 55 and 75 s, the following values were obtained: T_1=38.3 and 40 ºC, T_2=37.0 and 37.7 ºC, and T_3=36.7 and 37.4 ºC.

In accordance with equation (2) the value of the thermal conductivity of the nanoporous alumina measured in 55 and 75 s was the same and equaled to 1.56 W K^{-1} m^{-1}. The following raw data were used: the thickness of alumina 30 μm; the thickness of aluminum 0.8 mm; thermal conductivity of AA3003 alloy 180 W K^{-1} m^{-1}. This result agrees with literature data for the thermal conductivity of alumina 1.4–1.8 W K^{-1} m^{-1} [4-6].

CONCLUSIONS

It was shown that for the diode MBRB16H60 that had working current 6.0 A and power 3.4 W the diode die temperature measured in 250 s reached 128 and 67 ºC on the FR4 and aluminum circuit board, respectively. Thus, the temperature of die at the circuit board based on the aluminum with the layer of nanoporous alumina was shown to be 1.9 times lower than the one at the circuit board based on the FR4.

The thermal conductivity of the nanoporous anodic alumina layer was determined to be 1.56 W K^{-1} m^{-1}.

So, the proposed construction for the heat-conducting circuit board with copper conductors based on the aluminum with nanoporous alumina layer allows significantly increasing the efficiency of the heat dissipation from the circuit board elements and reducing their operating temperature. Therefore, active electronic components can operate at higher current, that is important in increasing the radiation efficiency of the powerful light-emitting diodes.

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