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# UTILIZATION OF CIRCUIT BOARDS ON ALUMINUM WITH NANOPOROUS ANODIC ALUMINA AND COPPER LAYER FOR POWER MODULES IN SWITCHING POWER SUPPLIES

I. Vrublevsky[1], K. Chernykova[1], V. Videkov[2], A. Tuchkovsky[1], T. Dinh[1]
[1] Department of Micro- and Nanoelectronics, Belarusian State University of Informatics and Radioelectronics, Minsk, Belarus
[2] Microelectronics Department, Technical University of Sofia, St. K. Ohridski blvd., 8, Sofia 1756, Bulgaria

**Abstract**: The paper represents the results of the studies on thermal efficiency of printed circuit board based on aluminum with nanoporous anodic alumina layer. It was showed that thermal efficiency of aluminum circuit board 0.6 mm thick with a layer of nanoporous anodic alumina 20 µm thick was close to the thermal efficiency of aluminum oxide ceramic 0.6 mm thick. The example of use of an aluminum base with a layer of nanoporous anodic alumina for fabrication of the power module of the switching power supply is described.

**Keywords:** printed circuit boards, aluminum base, nanoporous anodic alumina, thermal efficiency, power electronics, thermal imaging camera



## 1. Introduction

To guarantee the optimal thermal modes for operating electronic components with high heat generation, good heat dissipation should be provided. Solving these problems depends on the characteristics of circuit boards that are determined by both design peculiarities and their material. One of the solutions to decrease the thermal capacity of circuit boards is to apply aluminum substrates with nanoporous alumina to their design [1,2]. The thermal characteristics of such printed circuit boats are defined by heat conductivity of dielectric layer located between copper conductors and the metal base. Printed circuit boards with the metal base (Metal Core PCB) are used in devices with higher thermal loadings. The main fields of applications of such printed circuit boats are: LED techniques, power electronics and automobile electronics.

The aim of the present work was to study the thermal characteristics of aluminum plates with a layer of nanoporous anodic alumina by means of thermal imaging measurements. The efficiency of heat transfer in such design was compared to the one observed when a ceramic substrate was used. A carbon fiber filament heater was used as a heat source for one-sided heating of nanoporous alumina surface in the experiments [3]. The choice of such a design of the heater allowed for achieving a great quantity of heat generated upon a relatively small surface of the circuit board. Generation of a powerful heat flow along a narrow line section on the surface of circuit board was used to estimate the efficiency of the heat removal and thermal characteristics of dielectric material of the printed circuit board. An example of use of aluminum base with nanoporous alumina for fabrication of power module of the switching power supply is described below.

## 2. Experimental

An approach based on one-sided heating of a dielectric layer surface using a carbon fiber heating element was used for studying the thermal characteristics of the printed circuit boards. The reverse side of the circuit boat was temperature-controlled for thermal measurements by an external aluminum heat sink of a large area. The samples for investigations had the sizes 60x24 mm. The thickness of aluminum was 0.6 mm. For comparison of the thermal characteristics a ceramic substrate from the aluminum oxide 0.6 mm thick (heat conductivity of 27 W $K^{-1}m^{-1}$) and the printed circuit board from aluminum were investigated. The nanoporous anodic alumina layer 20 µm thick was formed on the aluminum surface by aluminum anodizing in a 0.2 M water solution of sulfuric acid at 14V. The surface morphologies of the porous alumina films were studied by a scanning electron microscope (SEM), model FEI Quanta 200F. Then the SEM images were analyzed by ImageJ software. The porous alumina films had well-ordered porous structure with pore diameter of 10.3 nm (Figure 1).

A carbon filament with the following dimensions: thickness of 80 µm, width of 0.5 mm and length of 75 mm was used as a heating element with an electrical resistance of 60 Ohm. The ends of the carbon fiber using the galvanic method became covered by the layers of the copper 10 µm thick. The carbon fiber was fixed on the surface of the samples by means of the reinforced layer of a prepreg with a thickness of about 80 μm before heat treatment.

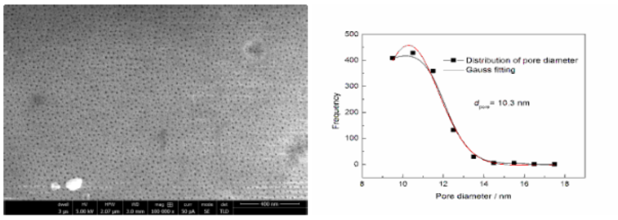


**Figure 1.** SEM image and results of analysis of nanoporous anodic alumina film on aluminum surface formed in sulfuric acid

The thermal field on the surface of printed circuit boards created by the carbon filament was studied by means of the MobIR M4 thermal imaging camera.

## 3. Results and discussion

Efficiency of heat removal is defined by the thermal resistance of a multilayered construction of the circuit board. In case of an aluminum base with nanoporous anodic alumina, the heat conductivity of aluminum and nanoporous anodic alumina (sulfuric acid) was equal to 180 W $K^{-1}m^{-1}$ and 1 W $K^{-1}m^{-1}$ [4], respectively. Figure 2 demonstrates a thermogram of the front surface of the circuit board of aluminum with nanoporous anodic alumina at 3.3 W and a profile of temperature distribution along the given line crossing the heater of carbon fiber.

As it can be seen from the thermogram, the thermal field had a uniform distribution over the surface of the circuit board. High efficiency of heat removal in case of such a construction can be explained by existence of a thin layer of anode alumina 20 μm thick. In the thermostating conditions of the reverse side of the aluminum circuit board, after heating for 30 s an increase in the temperature of the aluminum surface stopped and turned to saturation region (Figure 3).

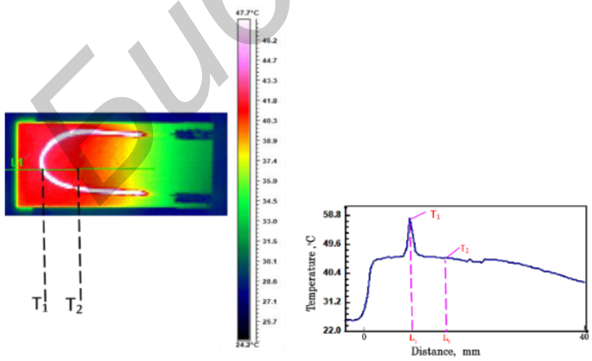


**Figure 2.** Circuit board from aluminum with the nanoporous alumina layer with the carbon fiber heater in the thermal camera (a); temperature distribution profile along the given line at the control points $T_1$ and $T_2$ measured in 45 s (b).

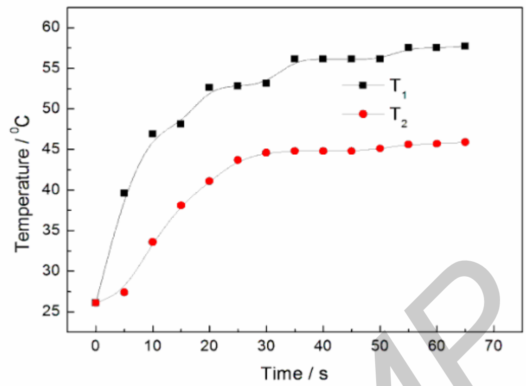


**Figure 3.** Change of temperature at the control points $T_1$ and $T_2$ as function of heating time for the aluminum circuit board with the nanoporous alumina layer at 3.3 W (Figure 2).

The temperature of the carbon fiber and surface of the aluminum circuit board after 45 s of heating were equal to 56.1 and 44.8 °C respectively. The temperature gradient of carbon fiber in regards to the surface of the aluminum circuit board was 11.3 °C. Figure 4 shows the thermogram of the front surface of the circuit board from aluminum oxide ceramics at 3.3 W and a profile of temperature distribution along the given line crossing the heater of carbon fiber.

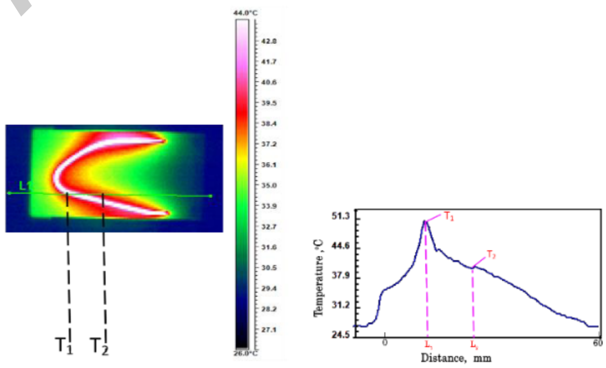


**Figure 4.** Circuit board of aluminum oxide ceramics with carbon fiber heater in the thermal camera (a) and temperature distribution profile along the given line at the control points $T_1$ and $T_2$ measured in 45 s (b).

In contrast to the aluminum circuit board, the thermal field on the ceramic surface had a non-uniform distribution. After heating for 15 s an increase in the temperature of the ceramic board surface stopped and turned to the saturation region (Figure 5).

The heated area was located along the heater line and heat transfer from a heat source took place in the form of a cone.

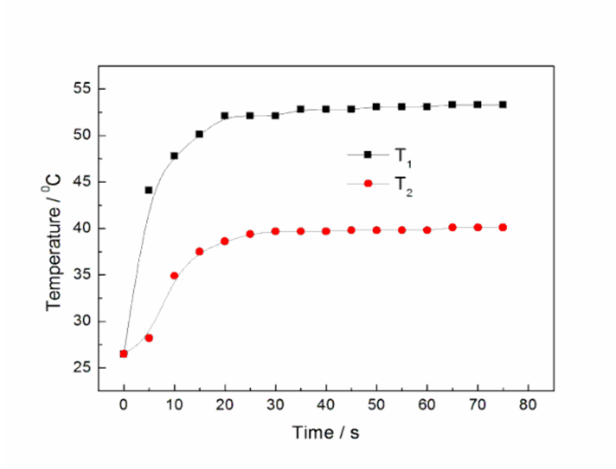


**Figure 5.** Change of temperature at the control points $T_1$ and $T_2$ as function of heating time for the circuit board from the aluminum oxide ceramics at 3.3 W (Figure 4).

The temperatures of the carbon fiber and surface of the ceramic board were equal to 52.8 and 39.8 °C, respectively. The analysis of obtained data for the temperature gradient of the carbon fiber showed that thermal efficiency of the aluminum circuit board 0.6 mm thick with the layer of nanoporous anodic alumina 20 µm thick was close to the thermal efficiency of the aluminum oxide ceramic 0.6 mm thick. A higher temperature of the aluminum base compared to the temperature of the aluminum oxide ceramics (higher with 5 °C) can be explained by the existence of anodic alumina layer 20 µm thick on the reverse side of aluminum. Such a layer of anodic alumina created additional thermal resistance on the way of heat transfer and as a result, the temperature of the aluminum base was increased.

The printed circuit boards for power electronics made of aluminum with nanoporous anodic alumina layer were fabricated with following technological route:

1. Aluminum substrate fabrication;
2. Aluminum chemical treatment;
3. Aluminum anodizing in a 0.2 M aqueous solution of sulphuric acid;
4. Lamel glueing onto the copper surface;
5. Assembling of the lamels onto the anodic alumina surface;
6. Creation of the intercircuit connections.

For the purposes of obtaining the quantitative characteristics needed for engineering of the printed circuit boards made of aluminum with nanoporous alumina layer, some examinations with active elements for determining the thermal conditions of operation were carried out. Test construction of circuit board topology was designed for mounting of 6 powerful switching field effect transistors (MOSFET, STW120NF10) (Figure 6).

The results of these examinations of a printed circuit board sample made of aluminum with nanoporous alumina layer for power electronics are represented in the Table.

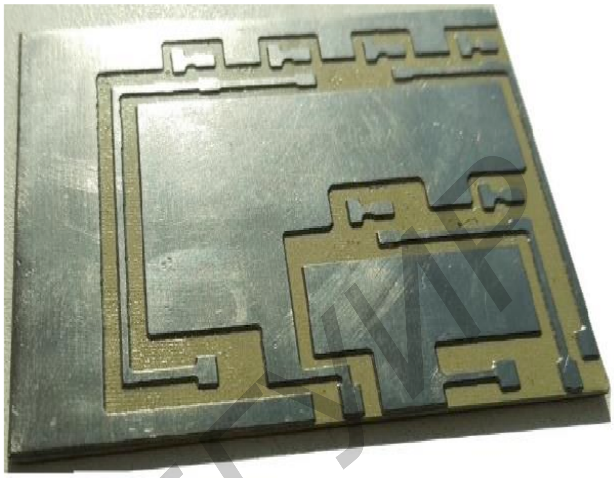

**Figure 6.** Front view of experimental sample of the printed circuit board on aluminum with the nanoporous alumina layer for mounting of 6 powerful switching field effect transistors.

**Table** Results of measurements of the main static parameters of MOSFET transistors (STW120NF10) on the circuit board from aluminum with the nanoporous anodic alumina layer and the copper layer 300 µm thick.

| Parameter | Value |
|---|---|
| Number of outputs | 8 |
| Resistance of the transistors, mΩ | 2.8 |
| Circuit resistance, mΩ | 8.9 |
| Power drop at the circuit board at operating current 20 A, V | 0.21 |
| Temperature of circuit board at operating current 20 A and hold up time 60 min, °C | 60 |

As it can be seen in the table data, construction of power printed circuit board made of aluminum provides the required thermal operation mode of power field effect transistors. Due to high thermal and electrophysical characteristics, printed circuit boards of aluminum with nanoporous anodic alumina layer can find various applications in power electronics, such as use in power supplies, inverters, DC/AC converters, power amplifiers and engine drivers.

## 4. Conclusions

The results of thermal investigations showed that thermal efficiency of the aluminum circuit board 0.6 mm thick with a layer of nanoporous anodic alumina 20 µm thick was close to the thermal efficiency of the aluminum oxide ceramics 0.6 mm thick. A higher temperature of the aluminum base compared to the temperature of the aluminum oxide ceramics (higher by 5 °C) was explained by the existence of the anodic alumina layer 20 μm thick on the reverse side of aluminum. Such a layer of anodic alumina created an additional thermal resistance on the way of heat transfer, and as a result, the temperature of aluminum base was increased. To reduce the thermal resistance of the aluminum circuit board, the layer of nanoporous anodic alumina on the reverse side should be removed.

Printed circuit boards made of aluminum with nanoporous anodic alumina layer can find various applications in power electronics for use in power supplies, inverters, DC/AC converters, power amplifiers and engine drivers.

**References:**

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