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SOLID STATE ELECTRONICS

Thermal-Conductive Boards Based on Aluminum with an Al_2O_3 Nanostructured Layer for Products of Power Electronics

E. N. Muratova[a,*], V. A. Moshnikov[a], V. V. Luchinin[a], A. A. Bobkov[a], I. A. Vrublevsky[b], K. V. Chernyakova[b], and E. I. Terukov[c]

[a] *St. Petersburg Electrotechnical University LETI, St. Petersburg, 197376 Russia*
[b] *Belarusian State University of Informatics and Radioelectronics, Minsk, 220013 Belarus*
[c] *Ioffe Institute, St. Petersburg, 194021 Russia*
**e-mail: SokolovaEkNik@yandex.ru*

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Abstract—The experimental results of electrical and thermal characteristics of circuit boards based on aluminum with a nanostructured layer of anodic aluminum oxide and copper conductors for assembling high-power field-effect transistors have been considered. It has been shown that the presence of a thin dielectric layer and thick aluminum base with high thermal conductivity provides a uniform distribution of heat generated by the active element over the entire volume of the board without formation of local regions with increased temperature. The experimental results have shown that the temperature gradient between the heat source and anodic aluminum oxide surface is about 17–18°C at a surface heat power of 4.4 W/cm^2.

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INTRODUCTION

To produce optimal thermal conditions for operating electronic components with high heat release, it is necessary to provide fast heat removal. This problem is urgent for many areas of electronics. So, e.g., the overheating of solar cells leads to deterioration in efficiency and reduces their life-time [1]. In power electronics, solving this problem is affected by parameters of a printed circuit board, which are determined by design peculiarities as well as materials [2, 3].

One method to reduce the thermal load of boards and to provide effective heat removal from active elements is the use of aluminum boards with a nanostructured anode aluminum oxide dielectric layer [4, 5], which is an ordered array of channels with given parameters (diameter, length, and distance between channels) [6–9]. This paper presents the experimental results of electrical and thermal characteristics of boards based on aluminum with the nanostructured anode aluminum oxide layer, which are intended for assembly and work with high-power field-effect transistors.

EXPERIMENTAL

The design parameters of power boards made for assembling high power electronic components are listed in Table 1. The experimental sample of a printed circuit board for power electronics, which is based on aluminum with a nanostructured aluminum oxide layer, is shown in Fig. 1.

The circuit boards were fabricated as follows.

1. Cutting of aluminum plates from an aluminum sheet.

2. Chemical treatment of aluminum.

3. Anodic oxidation of aluminum for formation of a nanostructured aluminum oxide layer on the aluminum surface.

Table 1. Design and geometric parameters of power boards based on aluminum with nanostructured aluminum oxide

Parameters	Values
Geometrical dimensions, mm	74–48
Thickness of a board without metallization, mm	1.0
Thickness of a copper conducting layer, μm	300
Surface protection	Soldering mask
Thickness of nanostructured anodic aluminum oxide, μm	50
Thickness of a solder pad based on reinforced epoxy, μm	30

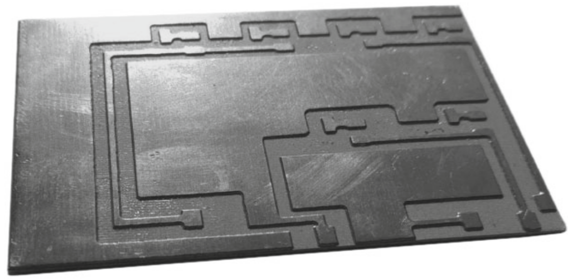

Fig. 1. Sample of a printed circuit board based on aluminum with nanostructured aluminum oxide for power electronics.

4. Gluing of solder pads to copper foil.

5. Gluing of solder pads to aluminum oxide layer.

6. Patterning of interconnections on copper foil.

7. Measurements of electrical characteristics of boards.

A carbon filament heater 0.2×7.5 cm^2 and having an electric resistance of 60 Ω (Fig. 2) was used as a heat source that provides one-sided heating of the surface of nanoporous anodic aluminum oxide. The generation of a high-power thermal flux by the heater with a linear shape was used to determine the efficiency of heat removal by the nanoporous anodic aluminum oxide.

This design of the heater allows one to obtain the conditions, under which a great amount of the released thermal flux falls on a relatively small surface of the circuit board (specific surface power of the heater is 4.4 W/cm^2).

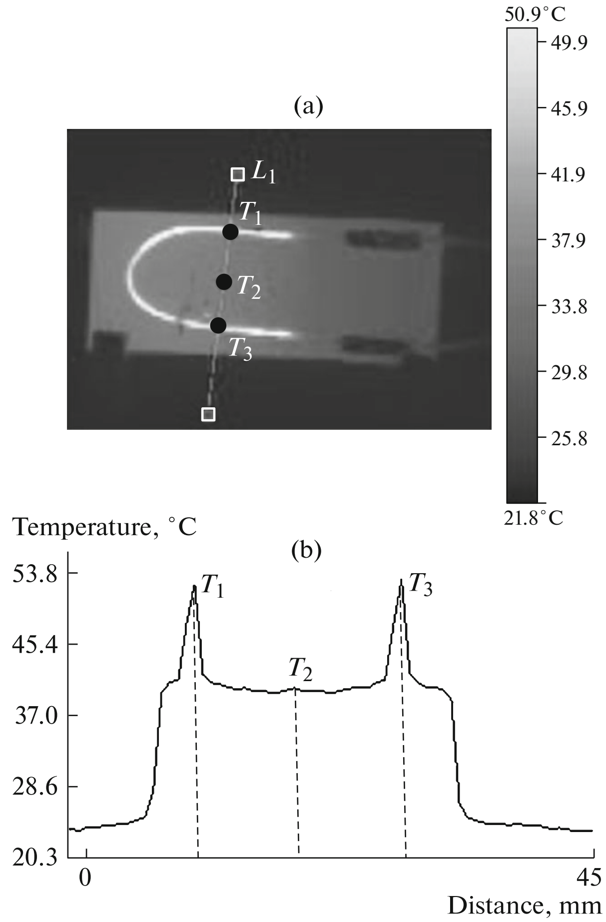

Fig. 2. Thermogram of surface of the board from aluminum with nanoporous aluminum oxide with a carbon filament heater (a) and temperature distribution profile (b) along the given line with reference point t_1, T_2, and T_3 for power of a heater of 6.7 W (measurement every 20 s).

RESULTS AND DISCUSSION

The uniform without local overheating distribution of a thermal field over the surface of an aluminum board with nanoporous aluminum oxide is shown in Fig. 2 for the case of a thermal source, i.e., the heater from a carbon filament. The gradient of temperature between the heat source and surface of anodic aluminum oxide is about 17–18°C at a specific surface heat power of 4.4 W/cm^2. The temperature gradient occurrence for a heater filament with respect to the board surface is associated with the limitation of thermal power, which can be transmitted through the layer of nanoporous anodic aluminum oxide. The analysis of thermal fields on the backside of an aluminum board did not reveal local overheating and showed that the temperatures in opposite points on the front and back sides of the surface were close (Fig. 3).

The results have shown that thanks to the high thermal conductivity of the aluminum board with a nanoporous anodic aluminum oxide layer the heat generated by the heater reaches the backside of the board with a high speed.

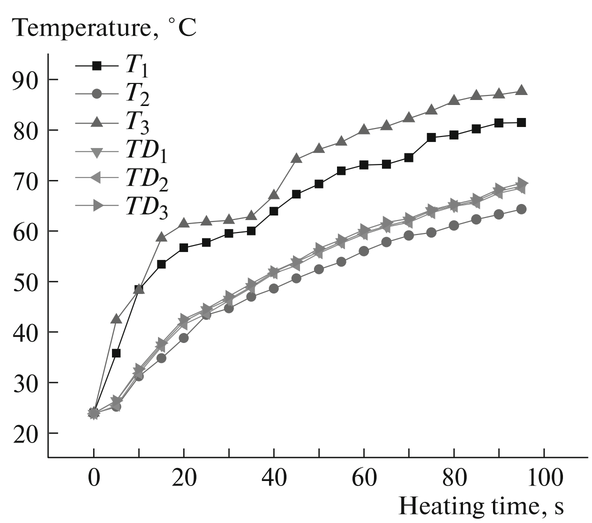

Fig. 3. Dependence of temperature in reference points T_1, T_2, and T_3 on face side (Fig. 2) and similar point TD_1, TD_2, and TD_3 on back side of the board as a function of the heating time for the board from aluminum with nanoporous aluminum oxide.

Table 2. Results of measurements of the main static parameters of switching DMOS field-effect transistors (2P835A-5) on the power board from aluminum with Al_2O_3 nanostructured layer and copper layer with a thickness of 300 μm

Parameters	Value
Number of terminals to a source pad	8
Resistance of open transistors, mΩ	2.8
Total resistance of a board, mΩ	8.9
Voltage drop across board at working current of 20 A, V	0.21
Temperature of board heating at working current of 20 A, keeping time is 60 min, °C	60

To obtain the quantitative characteristics of printed circuit boards, the experiments to determine temperature conditions for board operation were carried out using copper conductors with a thickness of 300 μm. The test topology of the board was developed for assembling six high-power switching n-channel field-effect transistors with a 2P835A-5 in-situ reverse biased diode, which were used in the form of non-mounted chips with 0.8 × 0.8 mm dimensions. According to the design documentation these transistors are intended for mounting by the method of surface assembly on cermet or aluminum oxide boards and used in power assembly in pulse power supplies with a specific power up to 7–8 kW/dm^3 [10] as well as in different RF converters.

The integrity tests of field-effect transistors were carried out after welding by ATsPOm-0.3 wire according to recommendations for chip assembly. The test results of boards are listed in Table 2.

As is seen from Table 2, the design of a power board based on aluminum with an Al_2O_3 nanostructured layer provides the desired thermal conditions for operation of high-power field-effect transistors. By testing circuit boards during experiments with six high-power field-effect transistors it was determined that the temperature of board heating for 60 min at a working current of 20 A was about 60°C.

The use of Al_2O_3 anodic film in the design of a board with small thickness and good thermal contact with the aluminum base led to the low thermal resistance of an aluminum circuit board. The use of power boards based on aluminum with an Al_2O_3 nanostructured layer provides the following advantages in comparison with conventional circuit boards based on FR4 dielectric: a decrease in the operating temperature of heat-releasing electronic components, reduction in board size, and increase in their mechanical strength. An important advantage of aluminum circuit boards is not needing radiators, which allows one to decrease the weight and dimensions of devices, to simplify their design, and to increase reliability.

CONCLUSIONS

As a result of studies it has been found that the temperature of board heating at a 20 A working current for 60 min is about 60°C. The temperature gradient between the heat source and anodic aluminum oxide surface is about of 17–18°C at a specific surface heat power of 4.4 W/cm^2.

Thanks to the high thermal and electrophysical characteristics, circuit boards based on aluminum with an Al_2O_3 nanostructured layer can be used in power electronics in power supplies, inverters, dc/ac converters, power amplifiers, and motor drivers.

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