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THERMAL PROPERTIES OF THICK FILM STRUCTURES RESISTOR ON DIELECTRIC

Описано результати дослідження теплових властивостей різноманітних товстоплівкових структур “резистор на діелектрику”.

The results of experimental investigations for thermal properties of thick-film structures “resistor on dielectric” are considered in the paper.

1. INTRODUCTION

The need for improvement of thermal management systems derives from several sources, of which ever increasing miniaturization is only one. What can be expected in increased thermal loads in even low temperature systems in the near future, can be gleaned from current activities in the areas of transistor size reduction and the simultaneous increase in area density. State-of-the-art of logic chips contains some $4x10^6$ transistors per cm^2 [1]. The semiconductor industry anticipates that the number of transistors on a chip, will double every three years. Accordingly, transistors will be nearly 10 times smaller and contain about 10 times the transistor count. The denser the integrated circuit the more power per chip and subsequently more heat. Network stations have power densities up to 40 W/cm^2 and planned next generation chips are expected to have heat loads $100<W/cm^2<400$ [2].

A lot of papers have been dealing with thermal management in electronic devices [2, 3]. Table 1 presents thermal properties of selected materials applied in electronics.

Table 1

Properties of selected materials applied in electronics

Material	Thermal conductivity (W/m*K)	Thermal expansion coefficient (ppm/^{o}C)	Dielectric constant
Silicon	75-150	2.7 3.5	11.7
Aluminum	238	22-24	-
Cu	400	17	-
Ag	422	19.7	-
Alumina (96%)	20	6.0 – 7.7	9
Alumina (99.6%)	27	6.5	10
Mullit	4 – 7	4 – 5	5.5 – 6.5
BeO	250	8	6.7
AlN	175 – 200+	4.1	8.5
Sapphire	40 – 45	3.24 – 5.66	9.4 – 11.5
Diamond	900 – 3200	1.18	5.68
c-BN	800 – 2000	-	-

Improved heat dissipation is also very important in new generations of MCM LTCC devices (Multichip Modules Low Temperature Cofired Ceramics). The circuits consist of several layers of low temperature cofired ceramics of low thermal conductivity (3W/mK). Heat dissipation in these devices are either through thermal vias filled with silver or gold [4] or by the liquid flowing through canals inside the LTCC structure [5].

Another solution could be to add the dielectric of high thermal conductivity, higher than a substrate, which would be able to dissipate heat from e.g. working resistor. Such model of heat spreader is presented by Balents [6] Fig.1. It could be seen from this picture that the addition of the layer of high thermal conductivity (2) causes heat spreading and dissipation. For comparison the small heat dissipation fron resistor placed directly on alumina substrate is shown in Fig. 1a.

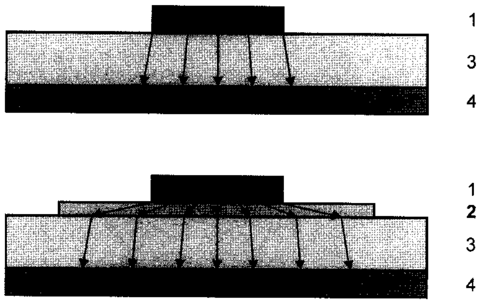


Fig. 1. The scheme of heat spreading and dissipation through the layers of different thermal conductivity: 1 – element (e.g. resistor) emitting heat, 2 – the layer of high thermal conductivity, 3 – substrate, 4 – heat sink (e.g. copper)

Our idea was to find a thick film dielectric layer of higher than alumina thermal conductivity. In contrast to the efficient heat spreading some applications need the presence of a thermal barrier becomes necessary to minimise power consumption due to heat losses behind the substrate.

The aim of this paper is to investigate thermal properties of different dielectric layers elaborated in our laboratory at ITME and their compatibility with thick film resistors placed on them.

2. STRUCTURES RESISTOR ON DIELECTRIC

The test pattern used for this investigation is shown in Fig.2. The alumina substrate (96% Al_2O_3) produced by CeramTec was 2x2 inches large and 0.63 mm thick. Two different dielectric layers were screen-printed on the substrate, one was D-421 (ITME) [5], the other one was c-BN based dielectric layer [6]. Both tests with the layers were fired at 850^{o}C, and then a resistor with its termination was deposited by the use of standard thick film process. Palladium silver P-202 (ITME)[7] and a resistive one based on ruthenium dioxide and lead-silica-aluminium glass was chosen to elaborate the structure resistor on dielectric [8]. For comparison, a structure where resistor was placed on bare alumina substrate was also prepared.

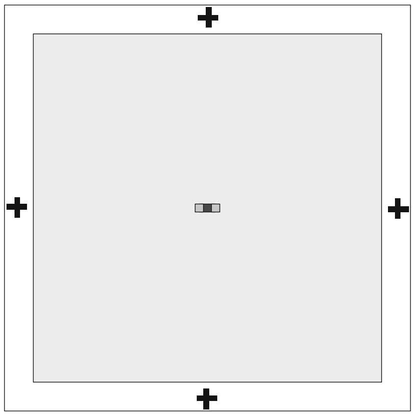


Fig. 2. Test pattern used in this investigation

All resistors were powered with 0.25, 0.50, 0.75 and 2.17 W and the distribution of temperature on the plate was investigated with the use of different techniques.

3. TEMPERATURE DISTRIBITION OF INVESTIGATED STRUCTURES EXAMINED WITH THE USE OF THERMOVISION CAMERA

Thermovision was used to measure heat dissipation on the structure „resistor on dielectric”. This technique allows to observe quick changes of thermal processes. The measurements were carried with the thermovision camera ThermaCAM SC1000 firmy Inframetrics (USA) with PtSi/CMOS 256x256 detectors working in the spektrum range 3,4 - 5µm. The thermal resolution was less than 0.1ºC.

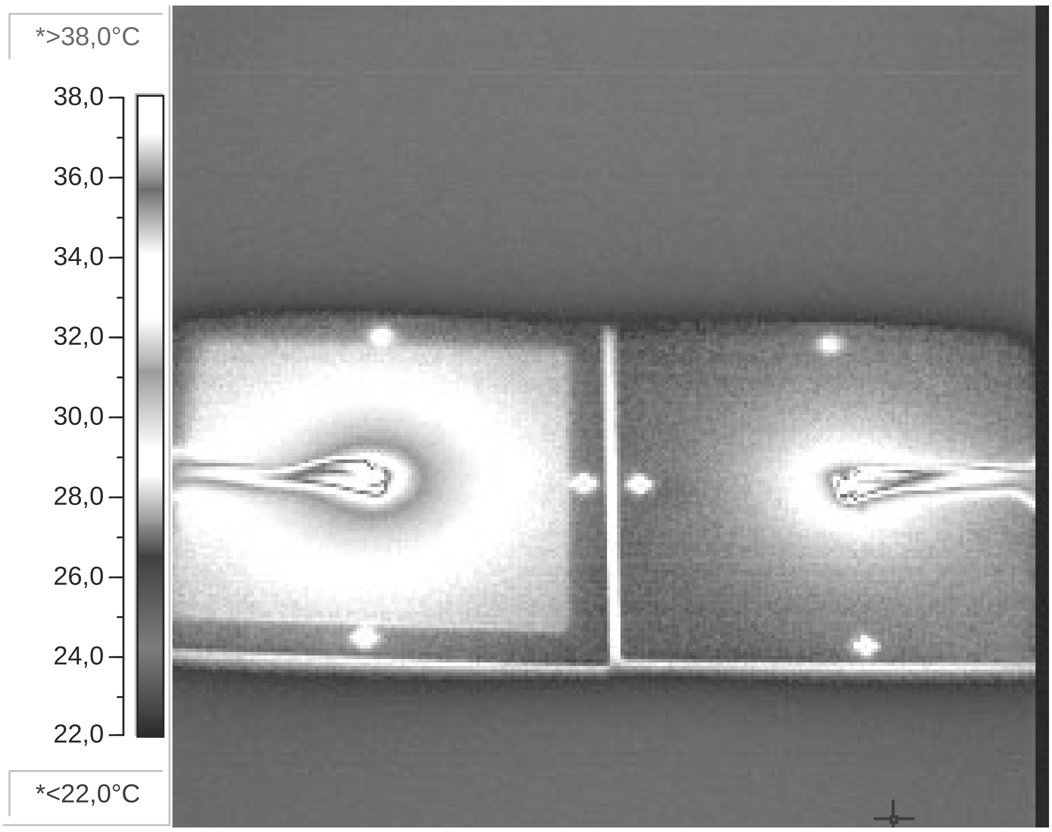


Fig. 3. Thermovision camera images of heat dissipation of 1mm square resistors on (left) c-BN on alumina and (right) directly on alumina. The resistor was powered with 500 mW

Fig. 3 and 4 presents thermovision camera images of heat dissipation of 1mm square resistors on c-BN and on D-421 layers on alumina and for comparison directly on alumina. The resistors were powered with 500 mW [8].

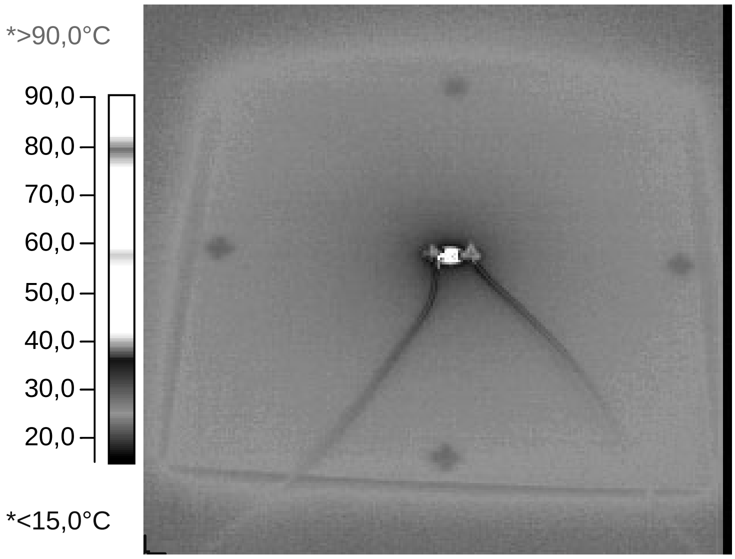


Fig. 4. Thermovision camera images of heat dissipation of 1mm square resistors on D-421 on alumina. The resistor was powered with 500 mW

Temperature distribution along the alumina substrate with the structure “resistor on dielectric” are presented in Fig. 5 and 6.

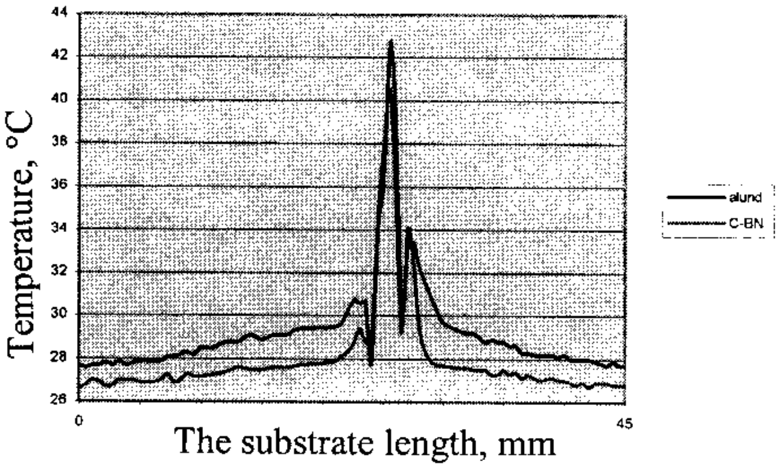


Fig. 5. Temperature distribution along the alumina substrate covered with c-BN layer and on bare alumina with centered resistor powered with 500 mW. The distribution was measured with the use of thermal camera

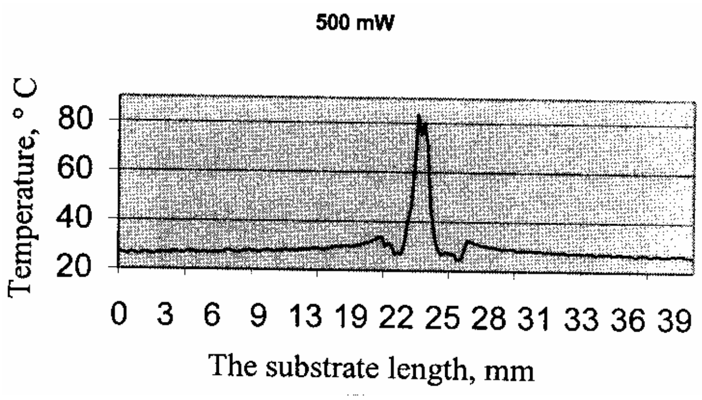


Fig. 6. Temperature distribution along the alumina substrate covered with dielectric laser D-421 and with centered resistor powered with 500 mW. The distribution was measured with the use of thermal camera

The figures 5 and 6 show that temperature of the resistor is the lowest when it is placed on c-BN layer, much higher when placed on alumina substrate, and the highest when on D-421 layer. These results are compatible with the images of heat dissipation in the investigated structures. The best dissipation of heat doming from the working resistor was when c-BN layer was added to the structure. When a layer of low conductivity was added (D-421) the heat was very poor.

4. MEASUREMENTS OF TEMPERATURE DISTRIBUTION IN THE INVESTIGATED STRUCTURE WITH THE USE OF SCANING METHOD

Another evidence for the efficacy of even the present c-BN thick films as thermal management systems, is presented in Figs 7. It shows the thermal profiles created by a resistive heat source (a one square mm resistor) on an 80 μm thick c-BN thick film on an Al_2O_3 substrate (A), on an uncoated Al_2O_3 substrate (B) and on an 80 μm thick D-421 thick film on an Al_2O_3 substrate (C). The power level in both cases was 25 W/cm^2. Note the uniform rapidly dissipating heat flux patterns for the c-BN coated samples.

Fig. 7 depicts a three dimensional presentation of the temperature profiles obtained with an I.R. scanner of an Al_2O_3 substrate (25x25x0.25 mm) equipped with a 1x1 mm square centrally located heater, top, and that for the same configuration but coated with an 80 μm c-BN or D-421 thick films, bottom. The central peak temperature for the uncoated sample reached ~220°C and for the coated sample ~160°C, a ΔT of 60°C, at a heater power of 2.17 W in both cases. The thermal profile incline for the Al_2O_3 only case, is clearly steeper than when a c-BN thick film is present. For the structure with D-421 layer the central peak temperature was ~240°C and the thermal profile was even steeper than for uncoated alumina.

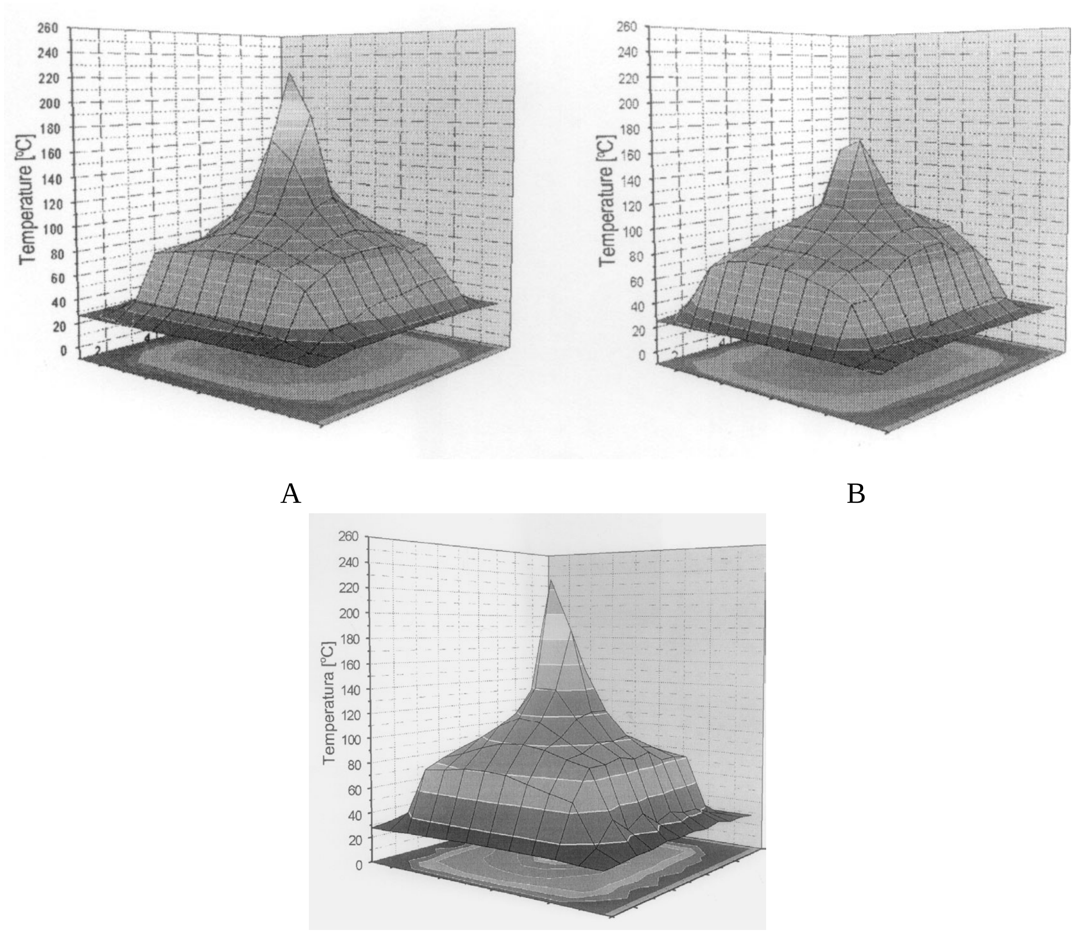


Fig. 7. Temperature distribution in the investigated structure measured by scanning method. The resistor powered with 2.17 W. A- the resistor placed on bare alumina substrate, B – the resistor placed on alumina substrate covered with c-BN, C – the resistor placed on alumina substrate covered with D-421

5. EMISSION OF INVESTIGATED STRUCTURES

Emission of the investigated layer was measured after placing a graphite layer on the top of the structure. The ratio of voltage between the graphite point and the point over the investigated layer is the measure of emission. The obtained results for dielectric layers: c-BN and D-421, resistive layer R-RuO_2 and alumina substrate (96% Al_2O_3) are presented in Table 2.

Table 2

Results of emission measurements of investigated layers

Type of the layers	Emission of layers.
Dielectric c-BN	0.95
Dielectric D-421	0.92
Resistive R-RuO_2	0.82
Alumina substrate	0.94

6. THERMAL CONDUCTIVITY COEFFICIENT OF LAYERS APPLIED IN INVESTIGATED STRUCTURES

Direct measurement of thermal conductivity coefficient in thick film multilayers was difficult. Traditional measuring methods could not be applied because the thickness of the layers was much smaller (less than 100 µm) than other dimensions of the structure (2 x 2 inches). That was why the authors measured heat transfer along the surface of the structure not along the cross-section of it.

Different experimental methods were applied. One group was the static methods, in the moment where the thermal conditions were stable. The difference of temperature of the two ends of the sample where one of them was heated was measured [10, 11]. The error of measurement was small, in the range of 5%. The other group of methods were the dynamic methods. The heat transfer was measured with the use of so called "laser flash method". In this method a great amount of heat is produced on one side of the structure by the laser source of heat and the temperature is monitored by the other side [12, 13].

The results are presented in Table 3. They are compatible when different methods were applied (for c-BN thick film layers) and with the previous measurements of heat transfer in the investigated structures.

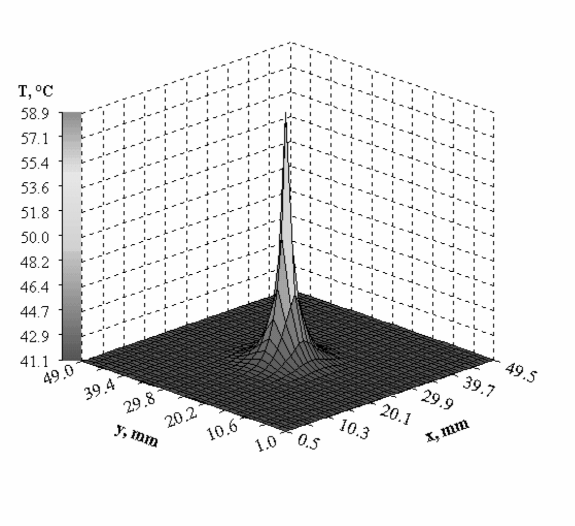
Table 3

Results of examination the thermal conductivity coefficient of investigated layers

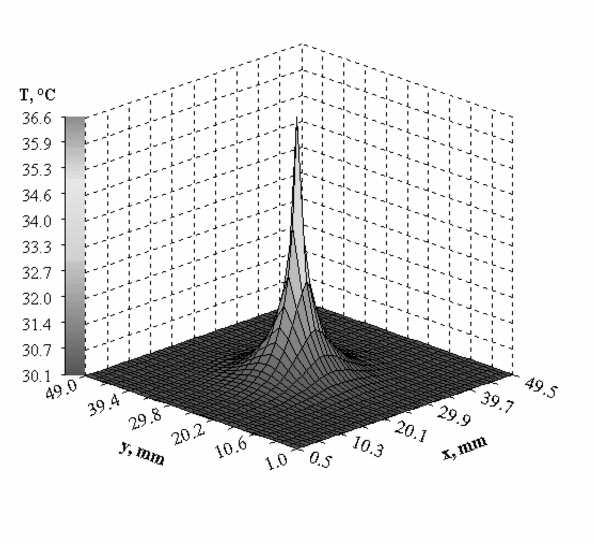
Type of the layer	Coefficient of thermal conductivity, W/mK	Measuring method
Dielectric layer of c-BN	100 – 140	Infrared thermography and laser flash method
Dielectric layer D-421	19	Infrared thermography
96% Alumina substrate	27	Table value
Air	263	Table value

6. COMPUTER SIMULATION OF THERMAL PROFILES

Computer simulation of the thermal profiles of a 1mm resistor on alumina and layers containing the highly conductive compound cubic boron nitride, c-BN, were made with the use of a programme Hybterm [14] and the contrast between the profiles is very clear. Unlike a normal dielectric such as D-421, the layer containing c-BN acts as a heat spreader and although there is no change in the heat actually leaving the substrate, the hot spot is sharply reduced. Figure 8 (a) and (b) respectively show in 3-dimensions the change in peak temperature between the resistor on alumina and on a c-BN layer containing 10% glass. Results on a layer of dielectric D-421 are shown in figure 8 (c).



A



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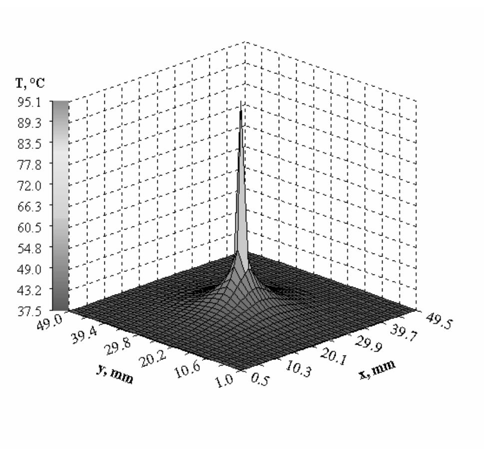

C

Fig. 8. Simulation of 3-dimensional heat distribution for a resistor dissipating 0.75W on A – 96 % alumina, B – a layer of cubic boron nitride (c-BN), containing 10% glass on 96% alumina and C – dielectric D421

7. CONCLUSIONS

Preliminary examination of resistors in combination with dielectrics of high thermal conductivity indicate a potential for use in heat spreading. The layers based on cubic boron nitride can dissipate heat quite effectively and as a result the temperature of a working element e.g. resistor is much lower.

In contrast to the efficient heat spreading observed when a thermally conducting filler is used in a dielectric, applications exist where the presence of a thermal barrier becomes necessary to minimise power consumption due to heat losses behind the substrate.

Further development work is necessary in order to evaluate whether there are materials interactions affecting the resistor properties in these structures.

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