CALCULATING THE INTERNAL THERMAL RESISTANCE OF BODIES THAT ARE CYLINDRICAL IN SHAPE

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Simulation is used to derive the thermal resistance of cylindrically shaped bodies as a function of their structural parameters. The results from the simulation have been generalized with an empirical formula.

The problem of calculating the internal thermal resistance of semiconductor devices with cylindrical containers can frequently be reduced to the calculation of the thermal resistance of isotropic and homogeneous constructions of cylindrical shape. The conversion methods are similar to those described in [1] for structures in the form of a parallelepiped.

In determining the internal thermal resistance R for bodies cylindrical in shape* we will assume the surfaces S and S_1 through which the heat flow passes to be isothermal. The surface S, at the end of the cylinder, is in the shape of a rectangle (Fig. 1).

A similar problem was solved in [1]; however, here the surface S is in the shape of a disk and instead of conditions of isothermicity at S we have assumed the condition $\partial T/\partial n = \text{const}$. Thus, the schematic representation of the heat-transfer processes, as given in this paper, makes it possible to encompass a broader class of structures and corresponds more fully to the physical sense of thermal resistance.

The quantity R was determined by simulation in an electrolytic bath. To eliminate the meniscus between the electrolyte and the rectangular electrode S, the latter was attached to a wide disk made of plastic. Prior to the measurement, copper was deposited on the electrodes to provide the required electrode surface finish. In all other respects, the experimental technique corresponded to that of [2, 3]. The maximum relative error in the test did not exceed 10%.

We were able to generalize the test results for the square electrode S by means of the empirical formula

$$R\lambda R_0 = \frac{d\left(\frac{D}{R_0}\right)}{\left(\frac{\sqrt{S}}{R_0}\right)^{1,1+0.036R_0/D}}. \tag{1}$$

The function $d(D/R_0)$ is found from the following formulas:

$$d\left(\frac{D}{R_0}\right) = 0.4\sqrt{2{,}03\frac{D}{R_0} - \left(\frac{D}{R_0}\right)^2} - 0.074 \tag{2a}$$

for $0.25 \leq D/R_0 \leq 0.75$;

$$d\left(\frac{D}{R_0}\right) = 0.4\sqrt{1.27\frac{D}{R_0} - \left(\frac{D}{R_0}\right)^2 - 0.073} + 0.023 \tag{2b}$$

for $0.074 \leq D/R_0 \leq 0.25$;

*In the following we will refer to R simply as the thermal resistance.

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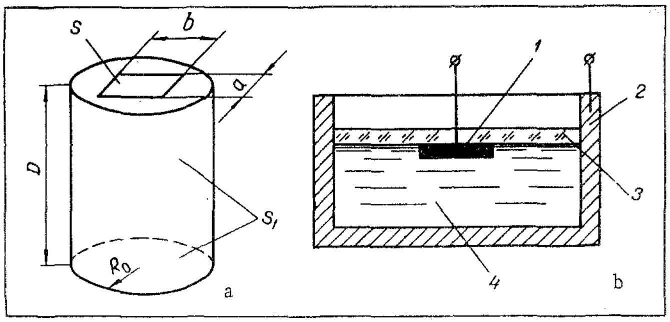

Fig. 1. Theoretical model for the determination of the thermal resistance (S and S_1 are electrode surfaces) (a) and a simplified construction of an electrolytic bath (b): 1) electrode with surface S; 2) electrode with surface S_1; 3) plastic disk; 4) electrolyte.

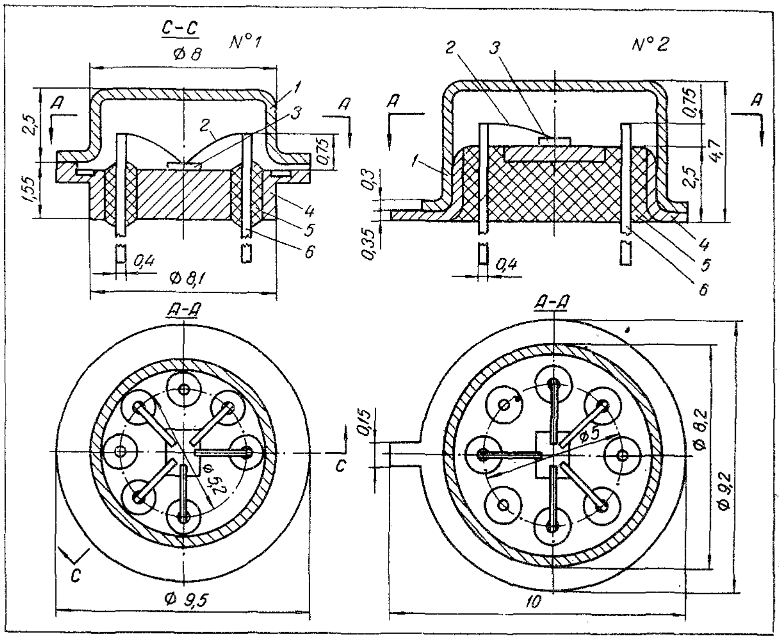

Fig. 2. Containers (Nos. 1 and 2) for TO-5 solid-state circuits: 1) lid; 2) crystal lead; 3) semiconductor; 4) base; 5) insulator; 6) container lead.

$$d\left(\frac{D}{R_0}\right) = 0.318$$

for $0.75 \le D/R_0 \le 1.12$.

Formula (1) has been derived for the values

$$0.092 \leqslant \frac{a}{R_0} \leqslant 0.917; \quad 0.074 \leqslant \frac{D}{R_0} \leqslant 1.12.$$

For values of $D/R_0 \ge 0.75$ the dimensionless thermal resistance $R\lambda R_0$ virtually ceases to depend on the dimensionless height D/R_0 of the cylinder. Relationship (1) can therefore be used even when $D/R_0 > 1.12$. The mean relative error in the approximation of the formula is 5.7%. The maximum error, which was observed at only a single point, amounts to 16%.

Formula (1) is used to determine the thermal resistance in the case of a square electrode. When the square electrode is replaced by a rectangular electrode of equal area, the thermal resistance diminishes only slightly. This reduction is an approximately linear function of the ratio of the sides b/a ($b > a$), amounting to 11% when $a/b = 0.25$.

The above theoretical relationships were derived for a uniform cylinder. Similar relationships were found for two containers of solid-state circuits and have gained the widest acceptance (Fig. 2):

$$R\lambda = \frac{0.4}{\sqrt{S}} \quad \text{for container No. 1} \tag{3a}$$

$$R = \frac{26.3}{S^{0.26}} \quad \text{for container No. 2.} \tag{3b}$$

Formula (3a) is valid when $0.04 \le \sqrt{S} \le 0.3$ and $0.45 \le a/b \le 1$; formula (3b) is valid when $0.04 \le \sqrt{S} \le 0.22$ and $0.45 \le a/b \le 1$. Here S is expressed, cm^2; while R is expressed, deg/W.

NOTATION

λ is the coefficient of thermal conductivity;
R_0 is the cylinder radius;
D is the cylinder height;
S is the area of contact between the square electrode and the cylinder.

LITERATURE CITED

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