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A Correlation of the Minimum Thermal Resistance at Soldered Joints

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IN an earlier Note[1] this author reported that thermal resistances for soldered joints ranged from 0.025°C-cm²/w for the best joint (brass/brass) to 0.14°C-cm²/w for a badly soldered joint. These values considerably exceed the theoretical value of 0.00246°C-cm²/w calculated for an average solder thickness of 15 μ. All the tests were performed with identical surfaces. Correlation of all of these data is very difficult because of the many parameters, both geometric and physical, that play a part in the resistance. This Note reports the results of a preliminary analysis and further experimental work done to obtain a correlation.

Thermal Analysis

It is assumed that the best soldered joints can be modeled as shown in Fig. 1. The solder (k_2) of average thickness e separates two solids (k_1,k_3) and is assumed to be homogeneous, devoid of gas cavities and scale. There is metal-to-metal contact between the solder and the solids at every point of the two interfaces $i1$ and $i2$. The surfaces of two solids are nominally flat but rough and the thickness of the solder is much larger than the surface roughness.

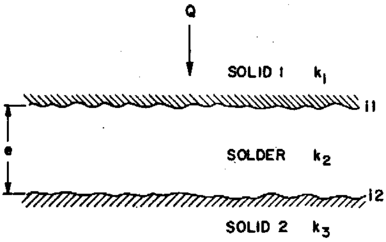

Fig. 1 Soldered joints.

The temperature fields far from the interfaces are unidirectional, parallel to the planes of the interfaces. In the vicinities of the interfaces and within the solder the temperature field is no longer unidirectional because of the waviness of the interfaces and the discontinuity of the thermal conductivity across the interfaces. The net result of this nonuniformity of temperature field is a measurable temperature drop ΔT_j at the joint. The thermal resistance at the joint is defined as $R_j = \Delta T_j/(Q/A)$ and can be written as $R_j = R_{i1} + R_{i2}$ where R_{i1} and R_{i2} are the interface resistances.

The thermal resistance at interface $i1$ is $R_{i1} = \psi_{i1}/k_{i1}$, where $k_{i1} = 2k_1k_2/(k_1 + k_2)$. The parameter ψ_{i1}, based upon current thermal constriction theory,[2-4] has the dimension cm and consists of a dimensionless geometric parameter and some characteristic dimension of the interface such as the surface roughness and the number of elemental heat flow channels available for heat conduction across the interface. The parameter ψ is assumed to be independent of thermal properties of the joint as well as the local heat flux. It will depend upon the surface roughness. The thermal resistance at the other interface can similarly be written as $R_{i2} = \psi_{i2}/k_{i2}$ where $k_{i2} = 2k_2k_3/(k_2 + k_3)$.

The total or joint resistance being the sum of the two interface resistances can be written as $R_j = \psi_{i1}/k_{i1} + \psi_{i2}/k_{i2}$. For identical surface conditions $\psi_{i1} = \psi_{i2}$ and so the joint resistance reduces to $R_j = \psi_i/K_j$ where $K_j = 2/(1/k_1 + 2/k_2 + 1/k_3)$. Here K_j is the effective thermal conductivity of a soldered joint consisting of three different materials having thermal conductivities k_1, k_2 and k_3, respectively.

Experimental Verification of the Theory

A series of tests was performed to verify the results of the thermal analysis. These tests consisted of temperature measurements in brass (k_1 = 1.11 w/cm-°C) and stainless steel (k_3 = 0.162 w/cm-°C) soldered with pure tin (k_2 = 0.64 w/cm-°C). The procedure followed is fully described in Ref. 1.

The first tests using brass/brass joints (K = 0.405 w/cm-°C) yielded a minimum resistance of 0.0245°C-cm²/w. The brass/stainless steel joints (K = 0.198 w/cm-°C) yielded a minimum resistance of 0.052°C-cm²/w and the stainless/stainless steel joints (K = 0.131 w/cm-°C) yielded a minimum resistance of 0.0805°C-cm²/w.

From these series of tests the parameter $\psi_i = [\Delta T_j/(Q/A)]K_j$ is calculated to have the values 0.0099, 0.0103, and 0.0109 for the three types of joints investigated. These values of ψ_i represent the average for ten sets of measurements obtained for each of the brass/brass, brass/stainless, and stainless/stainless joints. There was no observable variation of joint resistance with contact pressure.

Conclusions

The excellent agreement between the values of ψ_i obtained for the three types of soldered joints is a verification of the validity of the assumptions used. In these experiments the thermal conductivities differed by a factor of seven while the values of the effective thermal conductivity of the joints differed by a factor of three. One can conclude that the thermal resistance of a soldered joint can be correlated by means of the parameter ψ_i provided that the solder is homogeneous devoid of cavities and scale, and that ψ_i = 0.010 when the surface roughness is about 0.3 μ.

References

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