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Effects of the wire-bonding technique on the QFN16b's thermal performance. New correlations for the free convective heat transfer coefficient☆

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ABSTRACT

The technique of wire-bonding used in electronics is interesting for thermoregulation of the quad flat non-lead (QFN) packages during operation. To properly size these devices in the assemblies, it is necessary to know the surfacic thermal phenomena represented by the convective heat transfer coefficient. This is the objective of this work examining the thermal effects due to installation of wire-bonding on a QFN16. This particular device is named here QFN16b to differentiate it from the basic model without wire-bondings addressed in a previous study. During its actual operation, it generates a power ranging from 0.1 W to 1.0 W and it is welded on a printed circuit board (PCB) which could be inclined at different angles varying between the horizontal and vertical positions, according to the intended application. Calculations corresponding to 6 different areas of the considered assembly have been done by combining 20 powers generated by the QFN and 7 inclination angles. The distribution of the surface temperature and that of the source itself, as well as the free convective power exchanged by every area, are determined. Natural convective heat transfer is quantified by means of correlations which allow calculation of the average convective heat transfer coefficient in each area of the assembly and for all the treated configurations. They improve design, reliability, durability and performance of these conventional assemblies widely used in electronics in many engineering sectors.

1. Introduction

The reliability, durability, performance and correct operation of the systems are directly linked to their thermal state. The temperature is thus the main indicator for designing and maintaining the assemblies. This data is important in electronics given the strong integration of components which are increasingly small and powerful, generating volumetric heat fluxes of several GW m^3, including the most common applications where electronics are involved such as cell phones, computers and various domestic devices. There is therefore a clear need to control the heat transfer phenomena to ensure proper operation of these systems at different scales (macro, micro and nanoscales). This is particularly the case for the Quad flat non-lead (QFN) packages increasingly used in the electronic assemblies given their well-known advantages and low production cost with the modern techniques. Some manufacturing problems of these devices, such as deformations and cavitations are discussed in [1,2].

The conventional electronic assembly treated in the present survey is widely used in applications. It consists of an active QFN16 which could be welded in any position of a large printed circuit board (PCB) that could be inclined with respect to the gravity field. The assembly is fully subjected to natural convection. This heat transfer mode is privileged in applications and especially in electronics given its well-known advantages. Some surveys are carried out to enhance the convective heat transfer by using nanofluids [3,4]. The work [5] shows that particles of Copper, TiO_2 and Alumina added in water increase the heat transfer compared to those corresponding to only water. This is confirmed in [6]. The recent survey [7] presents some techniques improving the electronic components cooling.

The global heat transfer coefficient is quantified for a QFN32 device in [8] according to the effective power generated by the active package during its operation and the PCB board's inclination angle. Details of this coefficient and various aspects concerning the aerothermal phenomena are presented in [9] while those of the QFN16 are detailed in [10]. These works, however, concern conventional QFN devices whose characteristics are available in [11]. The work also confirms the limitations of using these packages for some combinations of the generated power and the PCB inclinations. Exceeding the maximum temperature recommended by the manufacturer can lead to malfunction, performance decrease and even shutdown and destruction, confirmed in [12]. In the case of a strong integration (high volumetric heat flux) leading to excessive temperatures, an alternative thermal solution is required, including the use of special components. Various techniques have been developed

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Nomenclature

g	gravity acceleration $(\mathrm{m\,s^{-2}})$
$\overline{h}$	average convective heat transfer coefficient for the QFN16b $(\mathrm{Wm^{-2}K^{-1}})$
$\overline{h'}$	average convective heat transfer coefficient for the QFN16 [10] $(\mathrm{Wm^{-2}K^{-1}})$
$k(\alpha), n(\alpha)$	coefficients of the $\overline{h} = k(\alpha)P^{n(\alpha)}$ correlation
P	generated power (W)
P_e	convective power exchanged on a given area (W)
P^*	power ratio defined by $P^* = P_e/P$ (−)
$\overline{R}$	average conductive thermal resistance $(\mathrm{KW^{-1}})$
R_M	maximal conductive thermal resistance $(\mathrm{KW^{-1}})$
$\overline{T}$	average temperature of the considered area (K)
T_M	maximal temperature of the considered area (K)
T_{Ms}	maximal surface temperature of the entire assembly (K)
T_c	temperature of the cavity's walls; initial temperature of the whole system (K)

Greek symbols

α	inclination angle of the PCB with respect to the horizontal (°)
δ	$\overline{h}$ deviation between exact and correlated values (%)
$\overline{\theta}, \theta_M$	dimensionless temperatures defined in Eq. (1), (−)
Θ	maximal temperature of the assembly for a given power P (K)
$\Theta_{\max}$	maximal temperature of the assembly for the maximal power $P = 1\mathrm{W}$ (K)

for the electronics industry. Several documents and works as [13–18] are dedicated to them while dealing with various aspects. The natural convection phenomena in closed enclosures concerning electronics are described in several works [19–22].

The wire-bonding technique frequently used in applications is discussed in this work. In summary, it consists in connecting the heat source of the component to its cold leads which are welded to the PCB. The bonding is done with wires constituted by associations of high thermal conductivity materials that could be Gold, Aluminium, Copper, Silver, or Nickel. There are several associations including Au—Au, Au—Al, Au—Cu, Au—Ag, Al—Al, Al—Ag, Al—Ni, and Cu—Al, according to manufacturers. Each one has advantages and drawbacks that could be found in the ample specialized literature. The junction temperature is then lowered around the surface-wire contacts, thus lowering the average temperature. This thermoregulation increases the component reliability and allows greater power integration. The wire-bonding technique has confirmed its performance and it is implemented in various assemblies. However, to the knowledge of the author, no work characterizing in detail the corresponding convective phenomena has been conducted. The literature does not contain tools to accurately quantify the convective heat transfer corresponding to the different areas of the device for the actual power generation range.

This is the objective of the present work examining the thermal effects of the wire-bonding technique in an assembly equipped with a QFN16 package with wire-bondings. This particular device is named here QFN16b to differentiate it from the basic model without wire-bondings addressed in [10]. This active component generates during its actual operation a power ranging from 0.1 W to 1.0 W. It is welded on one face of a printed circuit board (PCB) which could be inclined at different angles varying between the horizontal and vertical positions, depending on the considered application. Computations concerning 6 different assembly surfaces are made for various combinations of 20 powers generated by the QFN16b and 7 PCB's inclination angles. The distribution of the surface temperature and that of the source itself, as well as the convective power exchanged by every area, are determined. The natural convective heat transfer is quantified by means of correlations which allow to calculate the average convective heat transfer coefficient for each area of the assembly and all treated configurations. They improve the design and reliability of these conventional assemblies commonly used in electronic applications.

2. The considered assembly. Calculation method

The typical electronic assembly considered in this study is presented in Fig. 1(a). The active device is a QFN16b that is, from outside, a parallelepiped of square section (4 mm side and 0.85 mm thick). Its mark on the PCB is presented in Fig. 1(b). The internal arrangement of the device is the same as for the basic model QFN16 addressed in [10] where the details may be consulted. However, the higher source face is connected to the leads via 16 wires of high thermal conductivity of 25 μm diameter (Fig. 1(c)). The surface-wire contacts are regularly distributed on the source face to optimize its temperature homogeneity and reduce as much as possible its value during operation. This junction is the hottest and must be controlled in order not to exceed the maximal temperature for the most unfavorable thermal and geometric combinations. The active package is welded on one side of a square PCB (50 mm side, and 1.6 mm thick). It could be placed in any position on the plate which is inclined with respect to the horizontal plane by an angle α varying between 0 and 90° as presented in Fig. 1(d). The entire assembly is subjected to the free convection, being installed in a large air-filled cubic cavity (900 mm side) to avoid the boundary effects. Air inside the cavity is isothermal at $T_c = 293.15\mathrm{K}$.

The work presented here is performed with the same method used in [10]. Nevertheless, the main elements are summarized in what follows. To determine the effects of wire-bondings on the device's thermal behavior, the assembly is decomposed into 6 distinct areas as represented in Fig. 1(a–b):

* the top face, the 4 sides and the back face of the QFN16b, denoted as (Q_T), (Q_S) and (Q_B) respectively;
* the top face (except the (Q_B) 's mark), the 4 sides and the back face of the PCB, denoted as (B_T), (B_S) and (B_B) respectively.

The thermal conductivities of the materials constituting the package are kept the same as in [10]: 120, 260, 260, 2.1 and 0.66 $\mathrm{Wm^{-1}K^{-1}}$ for the die, the diepad, the leads, the paste and the molding compound respectively, assumed as isotropic. That of the wires is set to 300 $\mathrm{Wm^{-1}K^{-1}}$, average value corresponding to the actual material associations used in this technique (Au, Ag, Cu). As the PCB board's thermal conductivity is anisotropic, its equivalent values are assumed to be equal to 20 $\mathrm{Wm^{-1}K^{-1}}$ in the plate's plane and 0.35 $\mathrm{Wm^{-1}K^{-1}}$ in its thickness. All these thermal conductivities are considered as constant and temperature-independent. The 3D numerical solution is obtained by solving the conventional system (continuity, momentum and energy) by means of the control volume method associated to the SIMPLE algorithm. Details concerning this aspect are available in [8]. However, the mesh with the QFN16b is different from that of the basic QFN16, due to the adjunction of wire-bondings. The shape, size and positioning of the wires require a complex mesh with several refinements due to the contact between Cartesian and cylindrical coordinates systems. The mesh around the wires and on the bondings has been the most time-consuming but necessary phase to avoid divergence calculations. A detail of this mesh is represented in Fig. 1(e). The optimized mesh determined to minimize the calculation time is constituted by 1,729,244 nodes. For comparison, the mesh corresponding to the basic component QFN16 addressed in [10] is of 358.955