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Influence of vapor phase soldering fluid Galden on wetting forces (tombstone effect)

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ABSTRACT

Vapour phase soldering brings besides many advantages for reliability in electronic production an increased incidence of tombstoning errors. The imbalance of wetting forces has a decisive effect on the tombstoning phenomena, and the changes in wetting forces during the vapour phase soldering are therefore analyzed and evaluated. Two types of solders (leaded Sn63Pb and lead-free SAC387 alloy) and two types of heat transfer fluids (Galden LS 230 and Galden HS 240) were used. The use of soldering fluids changes the surface tension equilibrium vectors for both used solders and changes the measured wetting force by up to 20%. The measurement was performed by wetting balance method using non-wetting sample.

1. Introduction

1.1. Vapour phase soldering

Plotog et al. (2010) reports that Vapour Phase Soldering (VPS) is an evolving method of reflow soldering which was firstly introduced by Robert Christian Pfahl and Hans Hugo Ammann in 1974. It is, according to Illés and Géczy (2013) an emerging alternative to conventional forced convection reflow soldering. The major advantage of this method is a uniform and highly efficient heat transfer without overheating, as Illés and Géczy (2013) and Géczy et al., 2015a states. Significant reduction of the profiling time may thus be achieved. Illés and Géczy (2013) reports that soldering vapours keep out oxygen and thus the oxidation during soldering is suppressed. This method also has some disadvantages. Krammer and Garami (2010) noted that the highly efficient heat transfer may cause problems due to rapid temperature changes on the board leading to cracks or void generation as Villain et al. (2000) confirms. A soldering medium (Galden, having boiling point above the reflow temperature of the solder) condenses at the PCB as soon as the board is inserted into the vapours. The condensation increases the rate of heat transfer, but it also changes the surface tensions. The wetting force of molten solder is thus influenced and this may lead to increased tombstoning as Dusek et al. (2013) states.

The heat transfer medium is completely inert and non-toxic. Géczy et al. (2015a) found that the heat distribution is nearly uniform on the whole assembly and the used temperature profile is usually linear. It is on the contrary difficult to achieve recommended profile of solder paste manufacturer. Géczy et al. (2011) demonstrated that this can only be done by sequential dipping of the PCBs into the vapours.

The Galden fluid is a specific product composed of perfluoropolyether substance (PFPE) and the boiling point may be chosen from the range of 55 °C up to 270 °C (Solvay, 2014) according to the melting point of the used solder alloy.

According to Prasad (n.d.), the technological disadvantage of the VPS process is the more frequent occurrence of specific defects such as wicking in leaded parts and tombstoning in chip components as Dusek et al. (2013) and Plotog et al. (2008) confirmed. All vapour phase systems can show a difference in component lift due to the fundamental nature of the process. The vapour transfers the heat energy to the surface of the board due to the condensation and phase state change from vapour to liquid. Willis (n.d.) further states that the liquid film may subsequently interact with the components and cause their movement.

1.2. Tombstoning

Biocca (2005) and Choon (1996) refers that tombstoning is one of many common, wetting related defects, arising in electronic manufacturing. A failure having some similarity to tombstoning is billboarding. Unlike tombstoning where a discrete component has one termination soldered and the other end is in the air, billboarding is indicated by both terminations being soldered, but with the component turned on its side. Billboarding is often traceable back to the placement process. The higher incidence of both tombstoning and billboarding is

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connected with increasing miniaturization of components and may also be caused by wrong placement pressure or misprints due to change of the PCB dimensions due to temperature difference as Geczy et al. (2013) notes. The wrong paste deposition, specifically its amount unevenness is a critical aspect. The amount of the solvent that needs to be evaporated from the larger deposit is higher; the amount of metal, which has to be melted is also larger. These two parameters will cause a delay in the start of the melting process and should the time delay be large enough, then, according to Theriault et al. (1999), tombstoning will become practically unavoidable. Tombstoning has also a relation to the PCB design (grounding and shielding is realized by larger metallic areas that also serve as a cooler) or chosen soldering process; the position and shape of some components may cause shading of certain PCB areas (specifically for IR soldering). All of this leads to uneven heating which increases the incidence of component's placement errors like tombstoning or billboarding.

Uneven heating may be reduced by the use of more efficient soldering techniques. One of them is VPS, but in such a case, the flowing soldering fluid during the PCB reflow, see Géczy et al. (2015a,b), may on the contrary cause an upward force that unweights the components and cause tombstoning errors. The reason for higher incidence of tombstoning with VPS is still unexplored.

1.3. Wettability and wetting force

Urbánek and Klabačka (1996) state that wettability as the main aspect of solderability is defined as an ability of solder alloy to properly wet the metal surface within defined time period. The spreading of a liquid droplet occurs if the surface tension of the substrate is higher than the surface tension of the liquid that is trying to wet the substrate, that is − if the surface tension vector of solid-gas (γ_{sg}) is higher than surface tension vector of solid-liquid (γ_{sl}) (see Fig. 1 below).

$$\gamma_{sg} = \gamma_{sl} + \gamma_{lg}.\cos\theta \quad (1)$$

where γ_{sg} is the surface tension vector of solid-gas, γ_{sl} is the surface tension vector of solid-liquid, γ_{lg} is the surface tension vector of liquid-gas and the θ is the angle between γ_{sl} and γ_{lg} vectors. For optimum wetting, the contact angle, θ must be minimized and therefore γ_{sg} must be maximized. Oxides and contamination lower the surface energy of the substrate. According to Frear et al. (1994), the most important function of the flux is to remove or disperse oxides and contaminants and thereby increase γ_{sg}.

Wetting quality belongs to key parameters in electronic manufacturing and many research works are therefore focused on evaluation of wetting quality in dependence on many factors. In the past the following parameters were evaluated: the influence of the atmosphere (low oxygen concentration) by Dusek and Urbanek (2006), the influence of thermal capacity of the sample by Dusek et al. (2014), its preheating or the influence of the surface − different surface finish by Harant and Steiner (2008) and Steiner and Harant (2006), its roughness by Novak and Steiner (2009), etc.

The wettability of the same soldering material may vary considerably, as it is strongly influenced by the surface condition of the substrate. Harant and Steiner (2007) found out that thin films of oxide, grease or organic contaminants can severely affect the wettability of a metallic substrate.

The pad and the component lead are the areas where wetting is required. Should the wetting be significantly non-homogenous (different) on the two leads of the component, then the surface tension that is created during the phase change of the solder paste may lift the other part of the component and the so called "tombstoning" or "Manhattan effect" occurs.

1.4. Meniscograph

One of the methods to measure wetting force is to use a meniscograph – a very precise instrument that measures forces that are acting on a sample that is dipped into a liquid, usually a molten solder. The time dependence of the force is measured and evaluated. If the specimen is wettable, then the sample is pulled in into the molten solder bath. On the contrary, non-wetting specimen is pulled away from the bath with an upward force (see Fig. 2).

The specimen is during the measurement subjected to time-variant vertical forces. These are the surface tension force and the buoyancy force, which are described in the work by Dusek and Urbanek (2008) by Eq. (2):

$$F_{wet} = F\gamma - F_b = P.\gamma.\cos\theta - \rho.g.V \quad (2)$$

where F_{wet} is the measured wetting force (N), $F\gamma$ is the surface tension force (N), F_b is the buoyancy force (N), P is the specimen perimeter (m), γ is the surface tension ($N\,m^{-1}$), θ is the contact angle on the solid surface, ρ is the solder density ($kg\,m^{-3}$), g is the gravitational acceleration ($m\,s^{-2}$) and V is the immersed sample volume (m^3).

The weight of the testing sample is automatically compensated at the beginning of the measurement, the measurement is thus sample weight independent. The measurement process using wetting balance method and measured wetting forces are depicted in Fig. 3.

2. Experimental part (method)

The influence of the VPS soldering fluid on solder surface tension change and wetting properties was studied. Solder alloys and VPS soldering fluids used in the experiment are in Table 1.

The wetting force measurement was conducted using a testing specimen made of drawn silica glass rod with a diameter of 2.3 mm that was immersed into the solder bath. The drawn silica glass was chosen due to its oxidation immunity, non-wetting properties against solder and surface smoothness. Therefore the specimen can be used repeatedly. The first experiment was based on measurement of pure solder bath only; the second experiment was conducted with solder bath covered by Galden film. The last experiment verified the influence of pure boiling Galden on the measured resulting force. The glass rod was cleaned before each measurement and was cooled to ambient temperature so that heat inertia from previous measurement could not influence subsequent measurement.

The measurement was done on Meniscograph apparatus GEC solderability tester Mk6^{A}, equipped with a custom-made jar (having smaller dimensions and being equipped with a scale level compared to original tank for molten solder) allowing more precise measurement with Galden addition. The schematic figure of three different above mentioned experiments provided with the description of individual surface tension vectors is shown in Fig. 4.

With the view to correctly interpret the results, a proper immersion depth had to be chosen. When the non-wetting testing rod is immersed into a liquid, then the buoyancy force corresponds not just to the volume of the immersed rod, but additionally to the cone-shaped area of liquid that is pushed away (see Fig. 4 above, left). When a certain level of immersion is reached, then the cone-shaped area on the liquid

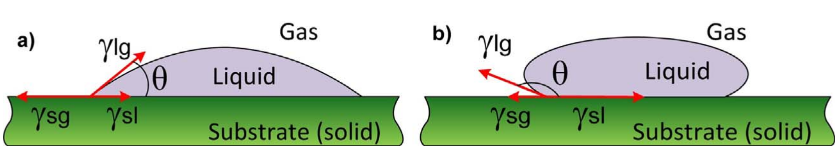

Fig. 1. Surface tension diagram (wetting equilibrium) for a) good wetting having acute angle θ, b) bad wetting situation, having open angle θ.

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