Elektronikus áramkörökhöz alkalmazható új automatizált kötési technológiák

Kutatási jelentés

ABSTRACT

In our experiment the reliability (life-time) of solder joints formed by Infrared (IR) and Vapour Phase (VP) soldering was investigated. A testboard was designed; and fifty pieces of 0603 (1.5 x 0.75 mm) size chip resistors were soldered onto it. For the soldering, profiles with the same $Q\eta$ factor (1000 s·K) were set for both the IR and VP method. After soldering, samples were aged by HAST (Highly Accelerated Stress Test) to determine the expected lifetime. The mechanical strength of the solder joints was characterized by shear-strength measurements, which were carried out on as-reflowed and on aged samples too. The shear strength was measured according to industrial standards; the shearing speed was 100 μm/s. Based on the measured shear strength values and the expected lifetime calculations, the reliability of the solder joints formed with Vapour Phase soldering proved to be better than those formed with Infrared soldering.

INTRODUCTION

Assemblers in progressive companies throughout the world are recognizing the advantages of Vapour Phase reflow soldering method as currently the simplest and most versatile method of soldering for small and medium size batches. During the Vapour Phase reflow process, the liquid called Galden boils, and a layer of saturated vapour forms above it. As the assembly (PCB containing the components placed into the deposited solder paste) is immersed into the saturated vapour, the vapour condenses onto its surface giving up its latent heat of condensation [1]. Vapour Phase soldering provides long-term reliable reproducibility of processing conditions [2]. Therefore, it can raise the attention of greater manufacturers as well.

In the literature few aspects of Vapour Phase soldering process has been studied so far. Since Vapour Phase soldering method is a continuously developing area even today especially for IMS (Insulating Metal Substrate) based electrical circuits. However, before the widespread of Vapour Phase soldering, at first, the reliability of solder joints formed with this method should be clarified. Unfortunately, in the literature there is no information regarding the reliability comparison of solder joints formed with Vapour Phase and conventional reflow processes. Only the effect of pad finish type on the reliability of solder balls formed with Vapour Phase soldering was investigated [3] and the creep behaviour of joints soldered with Vapour Phase reflow were studied [4]. Thus, we determined to perform research about the lifetime of solder joints formed with Vapour Phase and Infrared soldering method.

Experimental

To compare the Vapour Phase and conventional IR reflow soldering, experiments were performed, where 0603 size (1.5 x 0.75 mm) chip resistors were soldered with both of the heat transfer methods. After soldering, mechanical investigations and cross-section analyses were carried out. The designed testboard contains 30 pieces of chip resistors for mechanical measurements; and 20 pieces of them are intended for cross-section analysis and intermetallic layer thickness measurements. For the soldering, a lead-free SAC305 (96.5Sn3Ag0.5Cu) type 4 (particle size 25–36 μm) solder paste was used. It was deposited using a 125 μm thick laser-cut stainless steel stencil with a DEK248 semi-automatic stencil printer. According to the industrial standards, the printing settings were the following: 30 mm/s printing speed, 95 N squeegee force (300 mm long blade), 6 mm/s stencil separation speed. The components were placed with a TWS Quadra semi-automatic pick&place machine. The accuracy of the placement machine is ~50 μm. For the conventional IR reflow soldering, an Essemtech RO06 batch convection reflow oven was used, while an ASSCON Quicky 450 VPS machine was applied for the Vapour Phase soldering. The reflow profiles were set for both heat transfer methods to obtain a heating factor (1) [5] of 1 200 s·K and to get cooling rates within the recommended range of 2–5 K/s. In the case of slower cooling rates (<1.5 K/s), shrinkage defects were reported [6], and larger cooling rates can cause solder cracking due to CTE mismatches [7].

$$Q_\eta = \int_{t_1}^{t_2} \left(T(t) - T_l\right) \mathrm{d}t \,, \tag{1}$$

where $Q\eta$ is the heating factor [K·s], $T(t)$ is the measured temperature [K], $(t_2–t_1)$ is the time above liquidus [s], and T_l is the melting point of the alloy. The reflow profiles for the two heating methods are illustrated in Fig. 1.

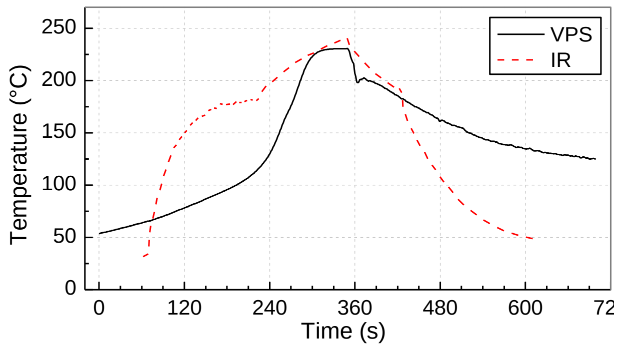

Fig. 1. Reflow profiles of the two heat transfer methods

After soldering, a part of samples was put aside for subsequent mechanical characterization, while the rest of the samples were subjected to life-time tests. The samples were subjected to Highly Accelerated Stress Test (HAST) up to 2 000 hours in an ESPEC EHS-2 chamber. The temperature of the HAST test was +105 °C with fully saturated (100%) relative humidity on +0.5 atm. overpressure. At last, the thickness of the intermetallic layer (IML) was measured on as-reflowed and aged samples for both heating method. To measure the intermetallic layer (IML) thickness, an image processing algorithm was developed. The algorithm was processed on cross-sectional images captured with Scanning Electron Microscope.

RESULTS

At first, the intermetallic layer of the solder joints was analysed in the SEM images of the cross-sectional samples (Fig. 2). Comparing the solder joints formed with the different heating methods, the intermetallic layer of Infrared melted solder joints is more scallop type, while the IML of Vapour Phase joints is more layer-wise; its surface is more even which can be due to the more even heating process with lower peak temperature.

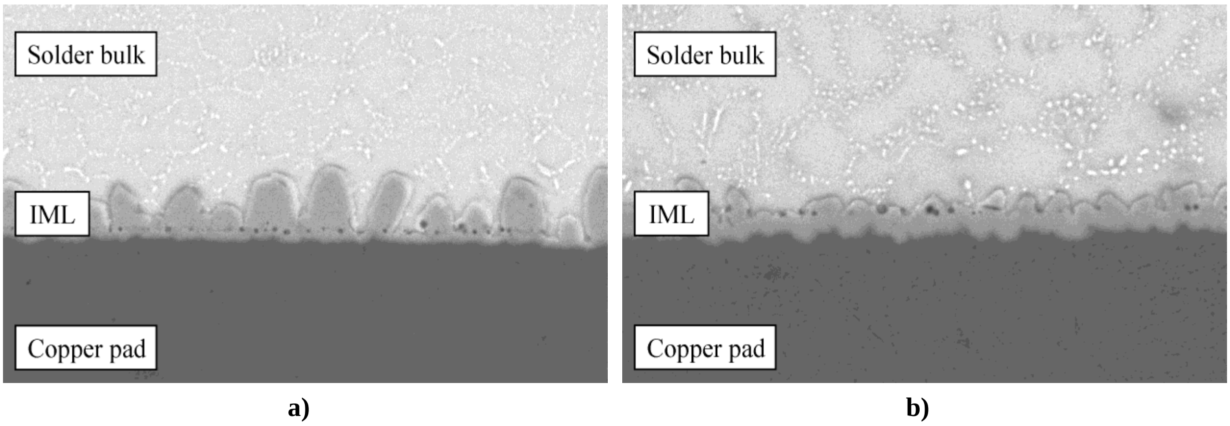

Fig. 2. The intermetallic layer of solder joints: a) Infrared heating method, b) Vapour Phase heating method

Studying the thickness of the intermetallic layers (Fig. 3.), a small decrease can be seen by the end of the first 400 h. The IML thickness decreases with 0.3 μm and 0.1 μm in Infrared and Vapour Phase samples respectively. This decrease can be traced back to the spalling of the IMC scallops into the bulk solder; that is why the decrement is larger in Infrared samples. By the end of 2000 hr. long HAST, a slight increase can be seen in the thickness of the intermetallic layers. The growth of Cu_3Sn intermetallic layer is much lower too. In opposition to [8], the Cu_3Sn layer is hardly observable even on samples aged for 2000h of HAST.

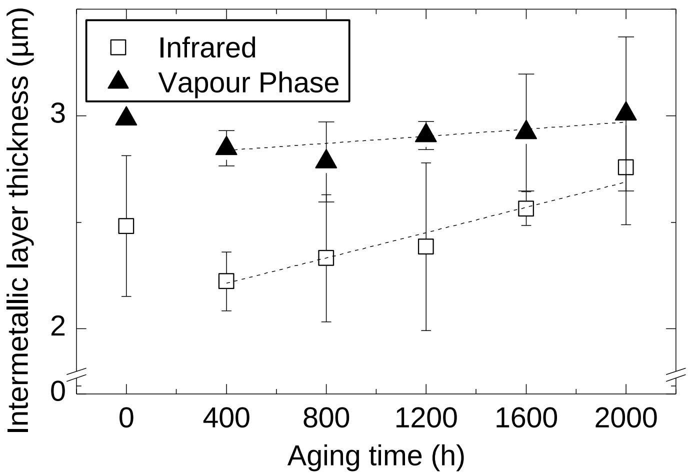

Fig. 3. Intermetallic layer thickness of the solder joints aged 2000h long of HAST

In addition to the intermetallic layer analyses, shear strength measurements were conducted on as-reflowed (0h) and on aged samples to obtain information regarding the reliability of the solder joints. Samples aged for 2000 hours were excluded because the main failure mechanism became the pad lifting instead of the solder joint crack. After performing the shear strength measurements, the failure rate (Fig. 4.) for the aged samples was calculated by defining the failure criteria as 80% strength to the shear strength of the as-reflowed samples according to industrial standards.

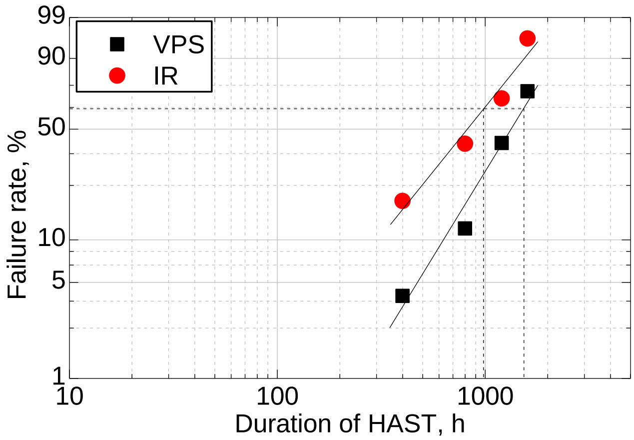

Fig. 4. Failure rate of SM resistors' solder joints

The result shows a slightly better reliability for solder joints formed with Vapour Phase soldering. The calculation of the characteristic life (duration until the failure rate of 63.2%) can be performed using (2):

$$x = 10^{\frac{\ln(-\ln(1-y)-c}{m}} \qquad (2)$$

The duration of HAST belonging to the failure rate of 63.2% (illustrated in Fig. 12 with dashed lines) is ~990 hours and ~1540 hours for Infrared and Vapour Phase soldered joints respectively.

Conclusion

In this paper, the reliability of 0603 size resistors' solder joints formed with Infrared and Vapour Phase soldering was investigated. The SEM analyses of the intermetallic layers revealed that the degree of layer increment is lower compared to other aging methods, e.g. Thermal Shock. The layer growth was 0.53 μm and 0.15 μm for Infrared and Vapour Phase soldering respectively and the Cu_3Sn layer cannot be inspected even after 2.000h of HAST aging. The failure rate for Vapour Phased solder joints is lower compared to Infrared formed joints. Considering the HAST Acceleration Factor as 493, the characteristic life is 488 000 and 759 000 hours for Infrared and Vapour Phase soldered joints respectively. The results strengthened the applicability of Vapour Phase soldering and could raise the attention of large manufacturer companies too to its application. It is strongly recommended for high-reliability circuits, especially for automotive electronics; and Small and Medium Enterprises (SMEs) can use Vapour Phase soldering technology too without doubt.

REFERENCES

[1] Strauss, R. SMT Soldering Handbook, Newnes, Oxford, England, 2nd ed., ISBN: 0 7506 1862 0, (1998)

[2] Willis, B. "Vapour Phase or convection for lead-free?", Global SMT & Packaging, December, pp. 4-6. (2008)

[3] Pietrikova, A. and Durisin, J. "VPS and reliability of solder joint", in IEEE 15th International Symposium for Design and Technology of Electronics Packages, Gyula, Hungary, 2009, pp. 395-398. (2009)

[4] Wiese, S., Wolter, K.J. "Creep of thermally aged SnAgCu-solder joints", Microelectronics Reliability, Vol. 47, pp. 223-232. (2007)

[5] Tu, K.N. and Zeng, K. "Tin-lead (SnPb) solder reaction in flip chip technology", Materials Science and Engineering, R, Vol. 34, pp. 1-58. (2001)

[6] Monlevade, E.F., Peng, W. "Failure Mechanisms and Crack Propagation Paths in Thermally Aged Pb-Free Solder Interconnects", Journal of Electronic Materials, Vol. 36 No. 7, pp. 783–797. (2007)

[7] Chavali, S., Singh, Y., Subbarayan, G., Bansal, A., Ahmad, M. "Cooling Rate, Pad Finish Effects on Mechanical Behavior of SnAgCu Alloys", 2011 Electronic Components and Technology Conference, Lake Buena Vista, FL, USA, 2011, pp. 424-430. (2011)

[8] Garami, T. and Krammer, O. "Investigating Micro-alloyed Solders with Thermal Shock Tests", IEEE 18th International Symposium for Design and Technology of Electronic Packaging, Alba Iulia, Romania, 2012, pp. 129-132. (2012)

Dr. Krammer Olivér

Budapest, 2015-01-05