APPLICATION OF LEAD-FREE SOLDERS IN AUTOMATED SOLDERING PROCESS

PRIMJENA LEMA BEZ OLOVA KOD AUTOMATIZIRANOG PROCESA LEMLJENJA

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Key words: automated wave soldering, lead-free solder, reliability, intermetallic compound

Sažetak: Lemljeni spojevi su vitalni dio elektroničkih sklopova. Ovi su posebno važni kod elektroničke opreme, posebno računala. Ubrzani razvoj te rastuća složenost elektroničke opreme uzrokovali su potražnju za visoko kvalitetnim, brzim, postupcima lemljenja pogodim za masovnu proizvodnju. Postupci lemljenja i oprema za lemljenje se pažljivo izabiru, uzimajući u obzir sve faktore uključene u postupak spajanja. Ekonomska prednost postupka lemljenja može se ostvariti samo ako je povezana sa visokom pouzdanošću. Postoje različiti postupci lemljenja. Izbor postupka ovisi o nekoliko faktora uključujući kompleksnost procesa, troškove opreme i proizvode.

Abstract: Solder joints are a vital part of an electronic assembly. These are critical to electronic equipment including computers. The rapid development and growing complexity of electronic equipment has forced the need for high-quality, fast operating, mass-production soldering methods. Soldering methods and equipment have to be carefully selected, taking into consideration all factors involved in assembly. The economical advantage of soldering process can only be realised if it is associated with high reliability. There are various methods of soldering. The choice of a method depends upon several factors including process complexity, equipment cost, and the products.

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1. INTRODUCTION

Proportion of electronic industry in overall consumption of lead makes around 1 %. In spite of that, the pressure aimed at a complete removal of lead from the products of this branch is ever increasing. These results in emphasis laid on a broader application of lead-free solders. Great attention is therefore devoted to research and development of alternative solders, mainly in the electronic and electrotechnical industries, where proportion of soldering occupies up to 90% of all joining processes. The ecological awareness of population in Europe, Japan and USA is strongly growing. That is why the manufacturers prefer the environmentally friendly products nowadays if the price does not differ too much [1, 2].

2. SOLDERING TECHNIQUES

In automated soldering of a printed wiring board (PWB), there are two basic methods: wave soldering and reflow soldering. The wave soldering method applies molten solder to the bottom side of a PWB. Application of solder and heating are done simultaneously in the wave soldering. In reflow soldering, however, solder paste is printed on a PWB before heating. A controlled amount of solder and flux is applied to the area to be soldered, which results in higher assembly yield. A common technique of applying solder and flux is to print a pattern of solder paste. Solder paste becomes an indispensable material for the electronics assembly process. Solder paste is a homogeneous mixture of solder powder, flux, and vehicle. It is applied on Cu pads or component terminals to be soldered with screen printing or dispensing process and can forma metallurgical bonding at a heating process. In the electronics industry, solder paste has a minor role in production volume compared with solder bars, but it plays an essential role as an interconnecting material in the surface mount technology (SMT) process. During the last two decades, solder paste has shown a prodigious progress in its performance, including printability of fine pitch pattern, rheological stability, and solderability. This has been done to meet market requirements toward high-density packaging. It allows for better soldering quality and high-density packaging when used for, for instance, 0.4-mm QFP (Quad Flat Package) and even flip chip assembly on organic carriers [1, 2].

2.1 Automated wave soldering

For the soldering of large series of printed circuit boards (PCB), the wave soldering is issued. The advantage of this method also lies in the fact that it can be used for combined mounting of the classic equipments with equipments for the surface mounting. Other advantages of this method are:

- greater productivity
- higher reliability,
- lower price.

At soldering of surface mount devices (SMD) with this method it is necessary at first to apply the adhesive bonding to join the PCB and electronic equipment. They are two ways to cure the adhesive: by the heat and by ultraviolet radiation. SMD components are located on the underside of printed circuit boards [2, 3]. The basic principle of the device for wave soldering is in Fig. 1 and Fig. 2.

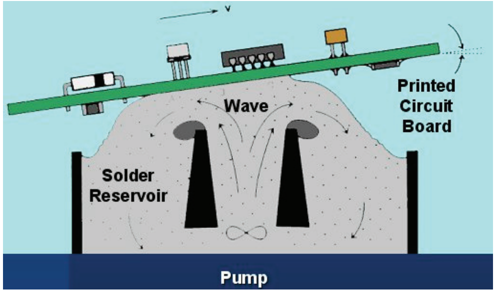


Fig. 1 The basic principle of wave soldering

Fig. 2 The automated wave soldering

2.2 Automated reflow soldering

It is a way of capillary soldering, in which all parts are warm. Suddenly can solder a few parts of the complex shape with different number of solder joints. According to the type of atmosphere can be used in the current atmosphere of solder or protective atmosphere, e.g. Nitrogen. Reflow soldering is carried out in reflow furnaces.

The reflow soldering in the furnace can be used by the following soldering technologies:

- IR heating,
- The vapors,
- Classic hot air heating,
- Hot plate (for ceramic substrates),
- Laser.

In the electronics industry is the most used method the soldering by conventional hot air heating. The advantage of this process is a uniform distribution of temperature in the furnace and the wide range of parameter changes soldering [2, 3]. Reflow soldering scheme is shown in Fig. 3.

Reflow soldering in the furnace (Fig. 4) is used for soldering of SMD devices that are fitted using by SMT.

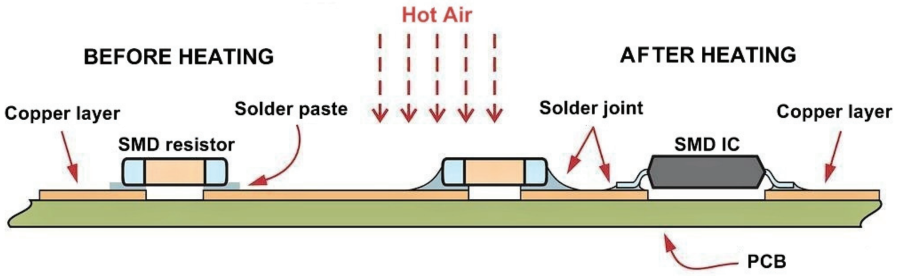


Fig. 3 Scheme of reflow soldering

Fig. 4 Automated reflow soldering

In addition to mass reflow soldering, PCBs are often subjected to a wave soldering operation, in which the entire board surface (one side) is exposed to a molten bath of solder. In through-hole solder applications, PCBs are passed over a molten wave of solder exposing the bottom side of the PCBs which may contain discrete components and through-hole leads to the solder bath. As the boards pass over the wave, solder is attracted to all wettable surfaces including attachment pads, component leads, and vias.

During automated soldering process, where more often used these two processes of soldering – the reflow and wave soldering is also increasing the quality of solder joints, because of the continual and repeated soldering process. Also it is decreasing the soldering time and it save the cost for whole production. Therefore it is necessary to use the lead-free solders which can save the long lifetime of soldered equipments. But during soldering is occur two processes, one is the dissolution of Cu in the lead-free solder and the second one is the creation and growth of intermetallic compounds (IMC) at the interface of Cu and solder. The growth of intermetallic compounds affected the reliability and lifetime of soldered joints. The measuring of IMC make possible to predict the reliability and lifetime of these components. In the next part of paper we discussed about the influence of the IMC to the reliability of joints [2, 3, 4].

3. SOLDER JOINT RELIABILITY

The basic requirement of solder interconnects is to form an electrical and mechanical connection between package elements that retains integrity through subsequent manufacturing processes and service conditions. Solder joints are also required to have the capacity to dissipate strains generated as a result of coefficient of thermal expansion (CTE) mismatches under service conditions over the lifetime of the assembly. Solder joint reliability is the ability of the interconnect to retain functionality under use environments. As the number of joints increase, and their size decreases, the reliability of solder joints becomes an issue because they are more difficult to manufacture and functionality requirements become stricter.

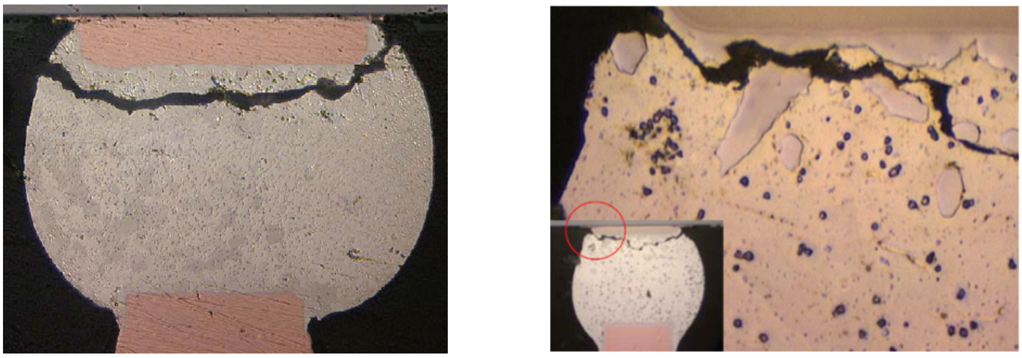
After assembly, solder joints must retain integrity when exposed to a variety of application conditions that include mechanical and environmental stress, either individually or in combination [4, 5].

3.1 Mechanical Shock

Shock can occur in an electronic package if an assembly is mishandled. A shock environment involves short-term exposure to high loads and is worse for heavier objects. For area-array solder joints, shock can be a problem for die-level interconnects if the die is directly attached to a heat sink and package-level interconnects in high-mass packages.

3.2 Thermomechanical Fatigue Behavior

Thermomechanical fatigue occurs when materials with different CTEs are joined and used in an environment that experiences cyclic temperature fluctuations resulting in imposed cycling strain. Thermomechanical fatigue is a major deformation mechanism concerning solder interconnects in electronic packages. Even small temperature fluctuations can have a large effect, depending on the joint thickness and CTE difference of the joined materials. After a critical number of thermal excursions, such as machine on/off cycles, solder joints experience fatigue failure.



a) b)

Fig. 5 Micrograph of BGA joints failed by thermomechanical fatigue behaviour: a) Micrograph of failed BGA joint created by Sn3.5Ag solder; b) Detailed view to the failed joint interface Sn3.8Ag0.7Cu solder / intermetallic compound.

Process of thermomechanical fatigue has a large effect on the microstructure, and microstructural evolution of solder joints. There is a thickening of the structure. Especially in joints made by SnBi (analogy with the classical SnPb) solder is possible to observe a significant thickening of the phases. The lead-free eutectic-based solders (Sn3.5Ag) experience thermomechanical fatigue damage and failure at tin grain boundaries (Fig. 5). The microstructural evolution in these alloys tends to be phase coarsening with minimal grain size coarsening. Sn-Ag-X alloys tend to have longer thermomechanical fatigue lifetimes than neareutectic Sn-Pb solders [2, 4, 5].

3.3 Thermal Aging

In service, electronic packages can be exposed to high temperature caused by the ambient temperature (under the hood of automobiles) or dissipated heat from a packaged device. The microstructure of solder interconnections can evolve to a coarsened structure that is weaker and interfacial reactions that form brittle intermetallics are accelerated.

3.4 Aging of Interfacial Intermetallics

Intermetallic compounds form between pad metallization and the active components of the molten solder (typically tin). For a copper metallization, the tin reacts to form Cu_3Sn and Cu_6Sn_5 intermetallics (Fig. 6). Depending on the kind of base metal or coating at reaction with Sn solder, the following intermetallic phases may be formed: Ag – Ag_3Sn, Ag_6Sn, Ni – Ni_3Sn_4, Ni_3Sn, Ni_3Sn_2, Fe –$FeSn_2$, FeSn, Au – $AuSn_4$, $AuSn_2$, Pd - PdSn4 and Pt - PtSn4 .

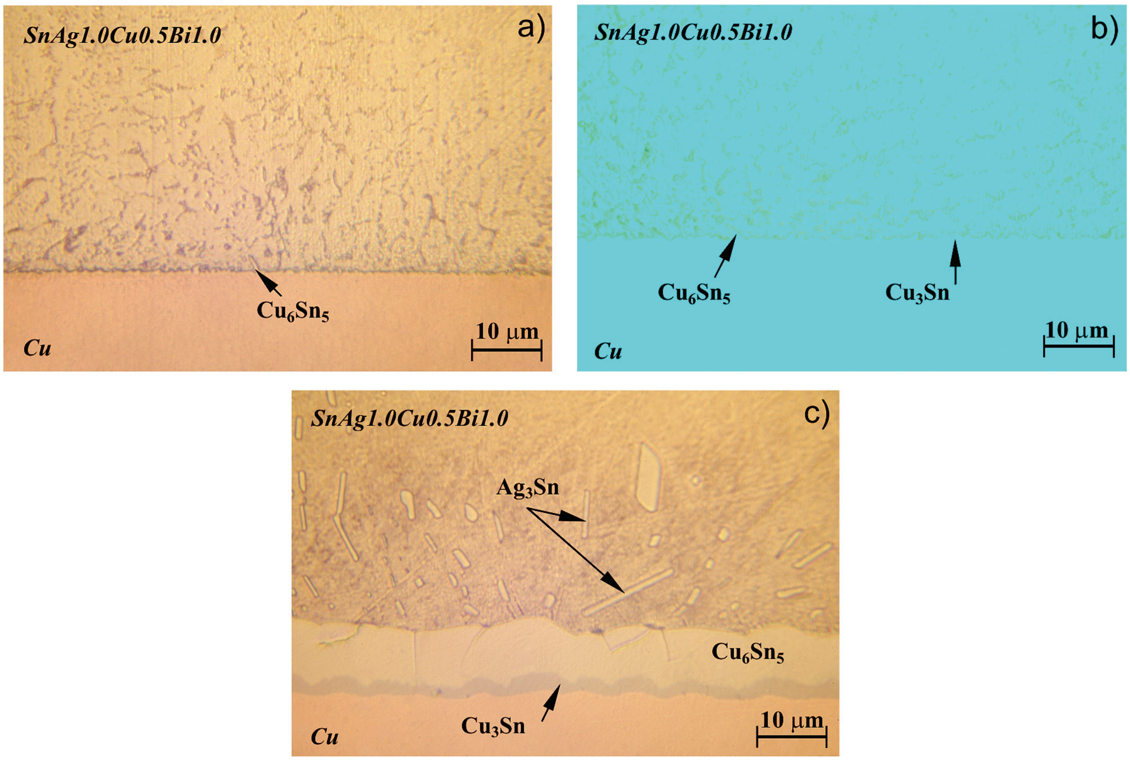


Fig. 6 Microstructure of the interfacial area of Cu-SnAg1.0Cu0.5Bi1.0 solder joint: a) after soldering T = 255°C, t = 5 s; b) aged at 160°C for 24 h; c) aged at 160°C for 360 h

After solidification, the intermetallic compounds continue to grow by solid-state diffusion. Over long periods of time, the intermetallic layers can grow to significant thicknesses (> 20 µm) and the solder/intermetallic interface may constitute easy sites for crack initiation and propagation. Excessive growth also consumes the base metal, or finish, that can result in the loss of adhesion to the underlying metal that is not solder wettable or create a plane of weakness owing to the stress generated from an intermetallic layer that is too thick. The metallized pad thickness generally must be greater than that consumed by the solder.

The transformation of solder-wettable coatings into intermetallics by solid-state reactions can also result in excessive intermetallic growth that degrades mechanical properties. The interfacial intermetallics are brittle and may fracture when strain is imposed, especially if the strain is tensile in nature. Solder joint interfacial intermetallics are brittle because they typically have complex crystal structures with few crystallographic planes available to accommodate stress by strain relief, i.e., plastic deformation via a slip mechanism. The failures are characteristically brittle and occur through the intermetallic or at the intermetallic/solder interface under low-load conditions [4, 5, 6].

In our experiments we enhanced the growth of intermetallic phases on the interface of SnAg1.0Cu0.5Bi1.0 – Cu joint by thermal effect. Annealing was performed in vacuum with temperature regulation accuracy ± 0,5 °C.

After soldering (Fig. 6a) is the structure of solders SnAg1.0Cu0.5Bi1.0 consisting predominantly with fine-grained structure. In the volume of solder are dispersed the phases Cu_6Sn_5 and Ag_3Sn which after the heat affecting change their shape and size. Given that the use of soldering materials based on Cu and Sn can be observed at the interface of Cu-substrate/solder creation of IMC Cu_6Su_5. Size layer of IMC does not get over 1μm. After annealed is created further reaction layer at the interface of substrate the phase Cu_6Su_5 documented as Cu_3Sn (Fig. 6b). From images (Fig. 6b, 6c) it is evident that with increasing annealing time increasing the thickness of the IMC at the interface and also causes to significant thickening of solders structure [6].

Growth of Cu_3Sn phase can be explained by the fact that the great thickness of Cu_6Sn_5 phase leads to diffusion of Cu at the interface and due to the lack of Sn at the interface of solder joint creation the phase rich in Cu (Cu_3Sn). Conversely, if the interface is located the Sn phase, due to the reaction Sn with Cu, growth of phase Cu_6Sn_5 is faster and reach the greater thickness. Morphology of the IMC is significantly different from each other. IMC Cu_6Sn_5 is initially characterized by its high inequalities in comparison with laminated Cu_3Sn phase. Over time, however serrated shape of Cu_6Sn_5 phase takes laminated shape with a unique layered scallop. For the longest time of 360 h of annealing (Fig. 6c) was a relatively continuous layer of the two phases with an average thickness of 22 μm. The thickness of the IMC in view of the mechanical properties of the phases can be considered large enough that the service is reliable [6].

3.5 Thickness measurement of the intermetallic phases

The measured values of thickness of intermetallic phases after soldering and subsequent heat affected solder joints made by lead-free solders SnAg1.0Cu0.5Bi1.0 are given in fig. 7. The rising temperature increases the thickness of the IMF, which confirmed waveforms graphs. The most significant increase, nearly identical in both solders can be seen in the phase Cu_6Sn_5. At temperatures of 100 °C and 130 °C, we can say that the intermetallic phase as well Cu_3Sn phase and Cu_6Sn_5 pursued with increasing annealing time linear growth kinetics. At 160 °C the thickness of two intermetallic phases, initially increasing linearly with annealing time, but after 7 days of the dependence changes to parabolic.

The first hypothesis assumed that intermetallic phase growing up to certain thickness and time linearly and due to a change of direction or skewers through the crack or pores there is a change to the parabolic dependence. After a long analysis concluded that after 4 days of annealing it is the degradation of solder joint. This phenomenon was observed especially at 160 °C. The critical thickness of the IMF, which causes the breakdown phase is 5 μm [6].

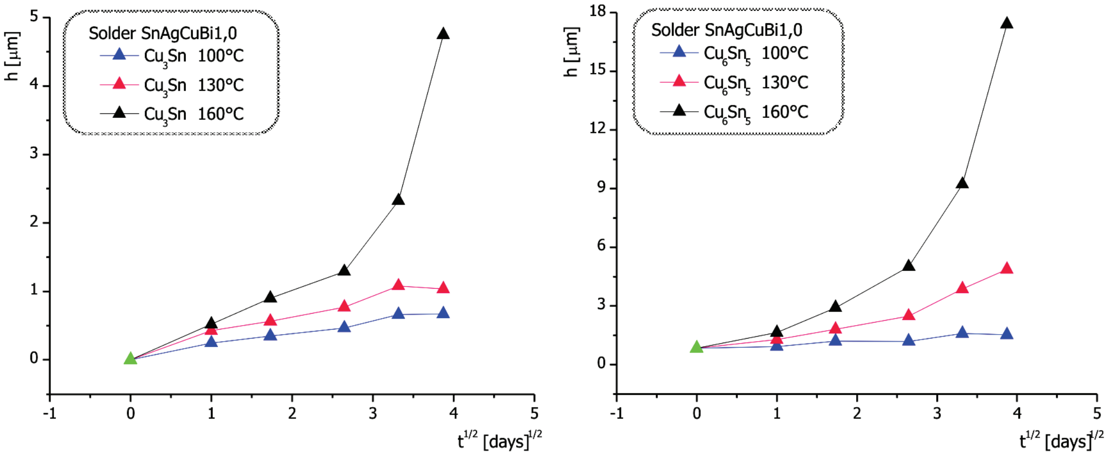


Fig. 7 Graph of the thickness of the intermetallic phase Cu_6Sn_5 and Cu_3Sn in dependence of square root of time for solder SnAg1.0Cu0.5Bi1.0

4. CONCLUSION

The aim of this paper was to show the dependence of the reliability and lifetime of lead free soldered joints by using the new automated soldering methods. The useful properties of materials are strongly dependent on their microstructure. The most critical soldering parameter that affects the initial microstructure in surface mount assembly is the cooling rate. A higher melting temperature for materials with different thermal expansion coefficients is very critical. It is very to apply the optimal soldering parameters especially the soldering temperature and soldering time for the prediction of solder joint reliability. It is also very important to observe the growth of intermetallic compounds created during the automated soldering methods in joints. The results of this work show the necessary to research the dependence of IMC growth and soldering process. Based on the results obtained at this work we recommend for further exploration of the lead free alloys and their properties in automated process and service conditions.

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