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Development of a Hybrid Microcircuit Test Vehicle for Surface Mount Applications

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Abstract

The technology drivers of the electronics industry continue to be systems miniaturization and reliability, in addition to addressing a variety of important environmental concerns. Surface mount technology (SMT) has evolved in response to these issues. Prototype hybrid test vehicles have been developed at Sandia National Laboratories to evaluate three lead-free solders for Au-Pt-Pd thick film soldering. The alloys are based on the Sn-Ag, Sn-Ag-Bi and Sn-Ag-Bi-Au systems. Populated test vehicles with surface mount devices were designed and fabricated to evaluate actual solder joints. Pastes were screen printed on the test substrates and reflowed with the components in place. The test components consist of a variety of dummy chip capacitors and leadless ceramic chip carriers (LCC's). The development of the reflow profiles will be discussed. Comprehensive defect analysis will also be presented.[1]

Key words: surface mount technology, hybrids, test vehicle, solder reflow

Introduction

Electronic components have been surface mounted to ceramic substrates for many years by the hybrid microelectronics industry, using printed film circuits. Surface mounting helps to meet the goals of electronic assemblies by reducing size, reducing cost and increasing reliability. The performance of a surface mounted assembly is superior to that of a conventional assembly, particularly at high frequencies. This is especially important for military and high-technology applications. As the technology of surface mounting has evolved, a range of packaging types has emerged. To fully implement surface mounting to its full potential, all components, active and passive, must also be surface mounted. They must also be physically downsized to meet packaging density constraints. If they are not, the product will fail to utilize the design benefits, such as size and weight reduction afforded by the use of surface mounting. Active components include transistors, diodes and integrated circuits (IC's) and are available in many different types of packages. Passive components include resistors, capacitors, inductors and connectors. Resistors and some capacitors in hybrid assemblies form part of the thick-film screen printed circuit. For surface mounted assemblies, small leadless components are used [1]. Thick film printed circuits are a less expensive, more flexible method of forming conductor circuits with resistor elements on a substrate. The circuit is screen printed to the substrate using special inks developed as conductors, resistors and dielectrics. By overprinting conductors with dielectric, a complex multilayer structure can be built up.

Surface mounting components can be joined to the printed circuit board (PCB) using a conducting adhesive, but the majority of assemblies are soldered. Conductive adhesives have substantially lower conductivity than metallic solders and this shortcoming has limited its use for component attachment [2]. Reflow soldering is the predominant method used for joining surface mount and mixed technology assemblies and is the process used in this paper.

Although tin/lead solder has been used by the electronics industry for many years for joining active and passive components, it has well documented environmental and toxicity issues. Several lead-free solders have been developed over the years to address these concerns. Tin-lead eutectic solder has adequate and well-known physical properties including a

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[1] Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-AC04-AL85000.

DISCLAIMER

relatively low melting point. New lead-free alloys must meet the requirement of both a compatible melting temperature and low toxicity. This reduces the number of metals that can be considered as possible alternatives [3]. Certain specialty solders are, however, being used for specific applications. For example, the Bi58Sn42 system has been used extensively in wave soldering of printed circuit assemblies. It is relatively inexpensive and has a low melting point. In general, tin, with its desirable physical properties, is alloyed with other metals to produce acceptable lead-free solders. These include, antimony, bismuth, copper, gallium, indium, silver and zinc. Each metal has its own specific advantages and disadvantages for incorporation into a lead-free composition. In addition, the limited solubility of a specific metal within a matrix of several other metals also complicates the design problem [2]. This paper examines the implementation of three lead-free solders into an alternative, all surface mount circuit board assembly.

Materials and Test Conditions

The hybrid test vehicle was a 96% alumina substrate with a Au-Pt-Pd thick film metallization. It measures 3.40" long x 2.50" wide x 0.040" thick. The Au-Pt-Pd film was double printed to a minimum thickness of 23μm and fired at 850°C. The test vehicle is illustrated in Figure 1.

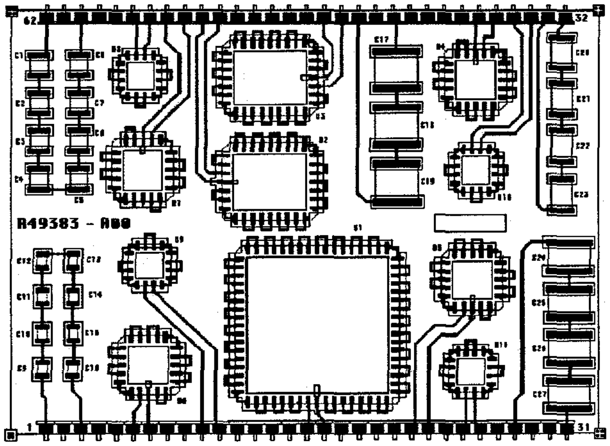

Figure 1. Schematic illustrating hybrid microcircuit test vehicle.

The circuit design has a daisy-chained configuration to permit the measurement of electrical continuity during testing. A dielectric was deposited around the metallized features [4]. The test components consist of a variety of dummy chip capacitors (0805, 1810, 1210, 1825 and 2225) and several sizes of leadless ceramic chip carriers. Chip capacitors have had a long development period due to extensive use of these components in the well established hybrid assembly technology. While screen-printable film resistors are easily incorporated in hybrid circuits, only limited capacitor values are achievable by thick or thin film technologies. Consequently, there has been a requirement for discrete surface mounting chip capacitors. The chip capacitors used in this study have 100% Sn terminations. The LCC's have gold castellations with 16, 20, 32 or 68 input/outputs (I/O's) with a 50 mil pitch.

The solder compositions (expressed as wt.%) used in this study included the commercially available pastes, Sn63-Pb37 and Sn96.5-Ag3.5. The other two alloys have the composition Sn91.84-Ag3.33-Bi4.83 and Sn86.85-Ag3.15-Bi5.0-Au5.0 and were developed at Sandia National Laboratories. A differential scanning calorimeter (DSC) determined the onset temperature to be 212°C [5] and 195° for the Sn-Ag-Bi and Sn-Ag-Bi-Au alloys respectively. They were fabricated as ingots at Sandia and subsequently processed into a powder 30-70 microns in diameter. The powder was mixed with an RMA-based flux vehicle to form a paste with a metals content of 90%. The reflow soldering operation used in this study involves screen printing the solder paste to the unpopulated test substrate with an 0.008" thick stencil. The components are then placed on the paste. The adhesive properties of the paste holds the components down while the board is heated to a temperature above the melting point of the given solder alloy.

Development of Reflow Profiles

The test vehicles were processed through a tabletop solder reflow machine. The system is ideally suited for all SMT and hybrid reflow soldering applications. The unit has four conduction heat zones; all of which had to be optimized for each solder alloy. The heat zones were fully inerted with technical grade nitrogen, flowing at a rate of 30 SCFH. A sweeper bar moves the part across the heat zones at a pre-determined speed.

The goal of any soldering operation is to achieve a time/temperature profile for complete reflow for each assembly and solder paste combination. It is important that the relationships between design, process and equipment variables be thoroughly understood to achieve optimum thermal profiles. There are many interactions between the solder paste, reflow time and temperature profile, SMT assembly, and equipment type [6]. The critical parameters for this test vehicle that were addressed were: 1) a 1.5 to 2 min. preheat, 2) spend approximately one minute above reflow temperature and, 3) the peak temperature must be 20 to 30°C above the melting point of the particular alloy for adequate solder reflow. Other concerns included the potential for insufficient flux activation, solder ball formation and possible component or board damage. Before populated boards with solder paste could be reflowed, bare alumina substrates with the exact same dimensions as the test vehicle were processed to develop the individual reflow profiles. Although attaching thermocouples to circuit boards is a time-consuming task, it is the preferred method for accurately monitoring the temperature of critical points on circuit board assemblies during the soldering process [7]. Four thermocouples were attached to the substrate with high temperature tape and the board was processed through the reflow machine. The thermocouples were then read by a battery-powered temperature recording device at a data rate of five points per second. This provided good information on initial settings. The next step was to place representative components on the alumina substrate. The thermocouples were again taped to the test board and processed through the reflow machine. There was a slight difference in the profiles with components on the board and the heat zone temperatures were adjusted accordingly.

The next step was to use the actual populated test vehicle to make final adjustments to the heat zone temperatures. At this point, a two-part, high temperature, high thermal conductivity epoxy system was used to bond the thermocouples to the substrate. The epoxy system gave a more representative reading of the topside temperature of the board. One thermocouple was placed under the large LCC, one under the medium LCC, one at the leading edge of the board and one at the trailing edge of the board. Several temperature adjustments were again required at this point due to the large heat sink of the components on the board.

The final heat zone settings resulted in good reflow profiles. They are listed below in Table 1.

TABLE 1. Temperature Profiles for Each Solder Alloy

SOLDER ALLOY	REFLOW PROFILE (°C)	SWEEPER BAR SPEED (in./min.)
SnPb	126, 200, 246, 100	7
SnAg	204. 210, 266, 100	7
SnAgBi and SnAgBiAu	150, 200, 260, 100	7

Results and Discussion

Each solder paste was printed on both populated and unpopulated test boards. The boards were then reflowed using the developed thermal profiles. Defect analysis consisted of visual examination under a stereo microscope of joint geometry, bridges, voids and component misalignment. Additionally, wettability of bonding pads, formation of solder balls and thermal damage to the board were assessed. The three lead-free alloys were compared to the well known properties of SnPb solder. The results are summarized in Table 2.

All of the unpopulated boards exhibited excellent wetting on all of the pads. There was no bridging of joints or voids in the solder. Although, the SnAg alloy showed some solder ball formation near the LCC pads, there was none near the chip capacitor pads. There did not appear to be thermal damage to any board, populated or unpopulated.

A completed test vehicle is illustrated below in Figure 2. The components have been soldered with the SnAg alloy.

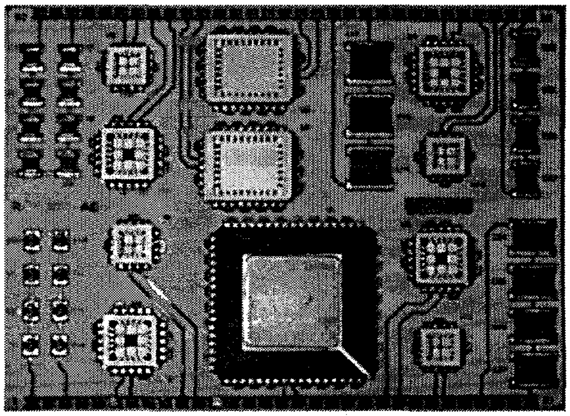

Figure 2. Hybrid test vehicle with components soldered in place with SnAg alloy.

Although the components were placed by hand, there was no misregistration on the pads. The populated boards exhibited a variety of minor defects. Most importantly, the first set of boards printed with each of the four alloys showed limited solder rise up the gold castellations on the LCC's. It ranged from approximately a 30% rise on the 16 I/O to 85% on the 20 I/O LCC. However, more solder rose up the castellations on the larger package, irrespective of position. All four sides of the LCC showed consistent wetting. The SnPb exhibited the best wetting, while the SnAgBi was the poorest. The test boards assembled with SnPb solder are illustrated in Figure 3. None exhibited 100% rise and the joints were very lean. This was not the case with the chip capacitors. All exhibited good wetting. After this initial observation, all subsequent LCC's were pre-tinned with the appropriate alloy prior to soldering. All LCC's showed much improved solder rise after pre-tinning. The visual results of the solder rise on a large LCC are shown in Figure 4. Figure 4a shows a LCC that was not pretinned. Much of the gold castellation is still visible, indicating that the solder has not wet the castellation completely. Figure 4b shows how pre-tinning of the LCC promotes excellent wetting and, therefore, better joints. This was the case for all of the alloys, but most dramatically for the SnAgBi.

There was also some non-wetting of the LCC pads, particularly in the corners. This was the case even after pre-tinning. The SnAgBiAu alloy exhibited the best wetting, followed by the SnAgBi and SnAg alloys. The SnAg alloy had the poorest pad coverage. No de-wetting was observed on any of the LCC pads or packages for any alloy. In all cases, the chip capacitors showed good wetting of the pads and packages. There was no de-wetting of pads or packages even without pre-tinning.

The only voids in the solder were noted in the SnAgBiAu alloy. These voids were very minor and appeared only on three types of chip capacitors. Although this alloy formed excellent joints, there was a grainy appearance to the solder on the stem while being shiny on the fillet. These results are illustrated in Figure 5.

The SnAg alloy exhibited the most dramatic lack of solder flow. This was especially the case with the LCC pads. Both the chip capacitor pads and packages had non-wetted areas. This is due either to the actual amount of paste deposited during the printing process or, perhaps, loading of Au from the thick film. Many surface mount components have gold terminations. Gold, however, has a very high dissolution rate and a high solubility at soldering temperatures. Gold can dissolve from the termination into a restricted amount of solder and attain relatively high concentrations. This is particularly important since it affects the liquidus temperature and, therefore, the flow properties of the solder. It could lead to potential defects such as bridging and icicling.

Conclusions

Prototype surface mount circuit boards were assembled with three lead-free solders: SnAg, SnAgBi and SnAgBiAu. The components included four types of leadless ceramic chip carriers and five sizes of chip capacitors. Although SnPb solder consistently yielded the best wetting and joint formation, the other lead-free solders offer potential for component attachment in surface mount technology. Wettability of circuit board features and packages was best with the SnAgBi alloy followed by the SnAgBiAu and SnAg systems. Current test results indicate that there is no single alloy to substitute for SnPb.

Acknowledgments

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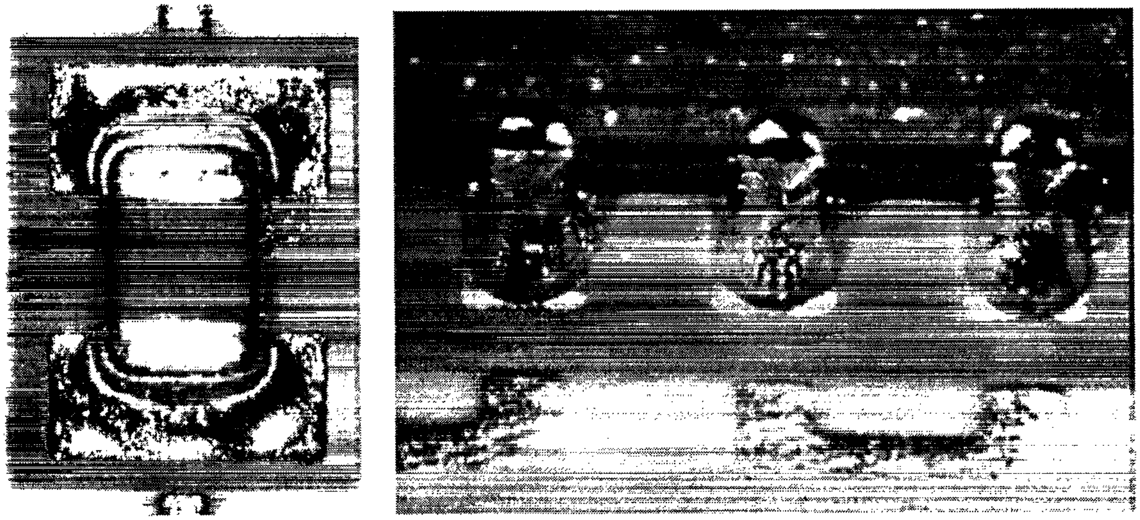
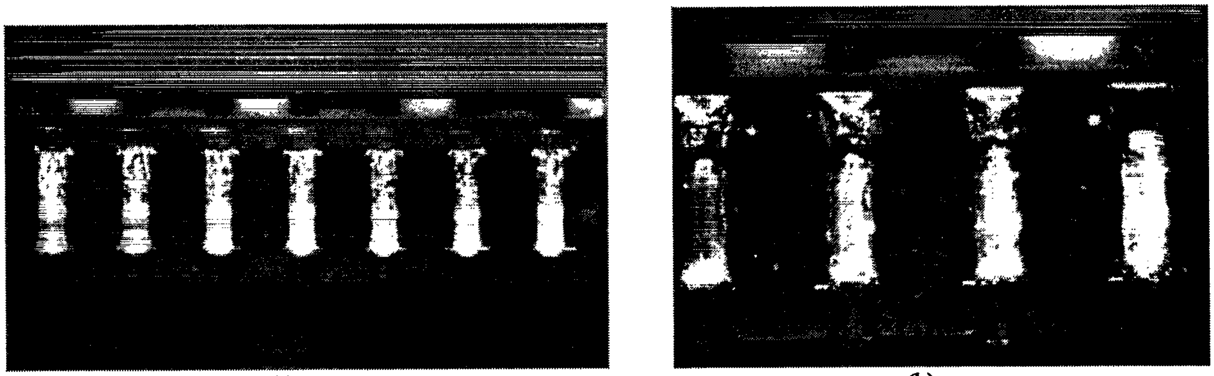


Figure 3. 0805 chip capacitor and 68 I/O LCC soldered with the SnPb alloy. Note the smooth appearance of the solder.



(a) (b)

Figure 4. Large LCC illustrating SnAgBiAu solder joints (a) before and (b) after pretinnning of Au castellations.

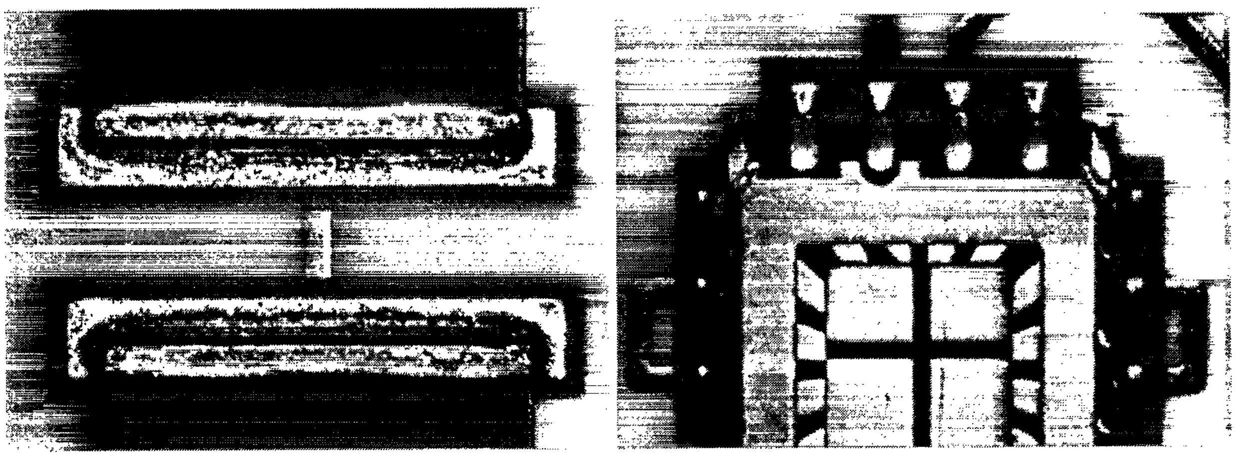


Figure 5. 2225 chip capacitor and 16 I/O LCC soldered with SnAgBiAu. Joints have a much grainier appearance although pads and contacts exhibit good joint geometry and good wettability.

Table 2. Defect Analysis of Hybrid Microcircuit Test Vehicle

(# of defects)

	SnPb									SnAg								
	LCCC Packages				Chip Capacitors					LCCC Packages				Chip Capacitors				
Type of Defect	68 I/O	32 I/O	20 I/O	16 I/O	2225	1825	1810	1210	0805	68 I/O	32 I/O	20 I/O	16 I/O	2225	1825	1810	1210	0805
Non-wetted pads	*	2	1	*						13	14	17	18		8	8	6	4
De-wetted pads																		
Non-wetted package										*					8	8	16	4
De-wetted package																		
Voids																		
Mis-registration																		
Solder balls										**								
Comments	*small non-wetted areas in corners of pads 40-80% solder rise before pre-tinning									*solder rise 35-80% before pre-tinning **some solder balls on 68 I/O LCC									

	SnAgBi									SnAgBiAu								
	LCCC Packages				Chip Capacitors					LCCC Packages				Chip Capacitors				
Type of Defect	68 I/O	32 I/O	20 I/O	16 I/O	2225	1825	1810	1210	0805	68 I/O	32 I/O	20 I/O	16 I/O	2225	1825	1810	1210	0805
												2	1					
Non-wetted pads			3	12														
De-wetted pads																		
Non-wetted package	*									*								
De-wetted package																		
Voids														1	2	1		
Mis-registration																		
Solder balls		**																
											**	**	**					
Comments	*30-55% solder rise before pre-tinning **some solder balls on 32 I/O LCC									*30-80% solder rise before pre-tinning **some solder balls on LCC's									