PROCEEDINGS
of the 1985
INTERNATIONAL SYMPOSIUM ON MICROELECTRONICS

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Introduction to the 1985 International Microelectronics Symposium

This International Microelectronics Symosium reflects the scope of technologies and international interest in microelectronics at the mid-point of the 1980's. At this time, microelectronics has developed a technology based on materials sciences, computer sciences, reliability engineering, and electronics. The papers published in these proceedings address this technology and its applications from semiconductor manufacture, hybrid assembly, and packaging up through multihybrid module assemblies. The broad international interest in microelectronics is shown by the inclusion of papers from nine countries, more than one-fourth of which are from outside the United States.

The 1985 Symposium Committee has designed this symposium to address a broad range of technologies with twelve technical sessions, seven courses on specific technological areas, two tutorials, and two open forums. In addition the exhibits add the dimension of materials and manufacturing to the symposium.

This symposium was developed for you by the 1985 Symposium Committee to stimulate the overall advancement of microelectronics through technological interchange. We hope that this symposium and its record in these proceedings meets this goal.

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ISHM encourages the exchange of information among the complementary technologies of ceramics, thin- and thick-films, semiconductor packaging, discrete semiconductor devices, and monolithic circuits. Microelectronics has developed into a distinct field of activities embracing materials, design, processing techniques and equipment, and fabrication and applications engineering. ISHM's technical meetings and publications reflect the full range of these engineering specialties.

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APPLICATION OF LASER MICROSOLDERING TO SMDS

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ABSTRACT

This paper will discuss the process development of laser microsoldering for the attachment of surface mounted devices (SMD) to printed wiring assemblies (PWA).

Topics to be discussed include: absorption and reflection of Yttrium-Aluminum-Garnet (YAG) and carbon dioxide (CO2) laser energy by printed wiring board (PWB) surfaces; effect of laser energy on PWB insulation; configuration, finish and solderability of component device leads and pads; and shear and pull test strength of laser soldered joints.

Graphics include: laser reflectance curves for PWB materials; scanning electron microscope (SEM) photographs of laser soldered joints on hermetic chip carrier (HCC) and on connector leads; cross section photographs of laser soldered joints; energy-dispersive X-ray (EDX) analyses on solder joint areas after peel and pull strength test data.

1.0 INTRODUCTION

SMDs are being used in ever increasing applications throughout industry and the military, both here and abroad.

Typical SMDs include flat packs, chip capacitors, chip resistors, HCCs, connectors, switches, solid state relays and potentiometers. Although they may have strain-relief leads, these leads are not inerted in PWB holes as is done with more conventional devices such as discrete transistors, axial leaded resistors, and dual inline packages (DIP).

All of these devices have one thing in common - they all must have excellent electrical contact with their support substrate, generally a PWB. This electrical contact is obtained by means of solder. However, since SMDs are soldered to - not into - PWBs, this means that solder must now also function as a structural material in addition to providing the necessary electrical connection.

Many different soldering methods are in use today for soldering conventional leaded devices to PWBs; however, not all of these methods are entirely suitable for SMD soldering. Manual soldering underneath a microscope is possible, but very tedious and labor intensive. Of machine soldering methods available, five will be addressed: 1) hot belt; 2) infrared; 3) wave; 4) vapor phase; and 5) laser soldering.

1.1 Hot Belt (HB) Soldering

HB soldering was developed by the hybrid microelectronics industry for soldering SMDs to ceramic substrates. Although this method is still popular, it has limitations of maximum substrate size, throughput, adequate heat distribution to devices with widely differing heat requirements, heat tolerance, and belt vibration.

1.2 Infrared (IR) Soldering

Focused and unfocused IR soldering of PWAs by means of high intensity quartz lamps, although popular for fusing tin-lead plate on PWBs, has not enjoyed wide usage for soldering PWAs because of difficulty with obtaining adequate heat distribution to devices without causing heat damage.

1.3 Wave Soldering (WS)

WS of PWAs has been the primary soldering method for leaded devices since the early '60s. Today, it has limited use with SMDs because of their need for adhesive or other mechanical attachment to the PWB prior to soldering and because of thermal shock to large ceramic packages.

1.4 Vapor Phase Soldering (VPS)

VPS has become quite popular since its introduction in 1975. Basically, this method involves exposure of a PWA to hot vapor over a fluid whose boiling point is slightly higher than that required to melt solder. Absorption of heat by the PWA causes the solder to fuse and form all solder joints simultaneously. The vapor condenses on the PWA, and the condensate then drains back into the boiling liquid for reusage. The most commonly used fluid is perfluorotriamylamine, better known as Fluorinert FC-70 (3M Company) (Ref. 1). This material boils at 215 degrees C/419 degrees F, which exceeds the melting point of tin-lead eutectic alloy by 32 degrees C/58 degrees F. Two types of vapor phase soldering systems are commercially available - the batch type and the inline. The batch type lowers the the PWA vertically into the hot vapor zone, pauses until solder fusion has occurred, then slowly raises the PWA out of the hot vapor to allow the molten solder to solidify. The inline type carries the PWA horizontally in one direction on a continuous open-weave, coated metal belt through the hot vapor zone and then through a cool down zone to allow the molten solder to solidify.

VPS of SMDs has a number of significant technical advantages:

1. Soldering is accomplished at a constant process temperature.

2. Because the solder on each PWA connection is molten at the same time, this method allows simultaneous solder joint formation.
3. Because of this simultaneous solder fusion, surface tension of the molten solder allows self-aligning orientation of 64-pad devices and smaller.

VPS also has a number of technical disadvantages:
1. VPS cannot be used with heat sensitive SMDs or PWB materials because the PWA is exposed to soldering heat for 30 to 90 seconds.
2. VPS, because of long heat cycles, forms dull, more brittle solder joints as a result of intermetallic compound (IMC) formation by tin in the solder with copper on the PWB pad.
3. VPS, because of heating PWAs to soldering temperature, initiates joint stress beginning with initial solder solidification. As PWAs cool to room temperature, joint stress continues to increase because of differing coefficients of thermal expansion (CTE) between SMDs such as HCCs and the PWB material (5.4 PPM/degree C for ceramic as compared with 18 PPM for polyimide (Ref. 2). This stress is additive to that contributed by PWB warpage during the heat/cool cycle.
4. VPS is generally not applicable to heat sink assemblies because the heat sink prevents attainment of proper PWA soldering temperature. Furthermore, if the heat sink is a heat pipe, the long exposure to elevated temperature will destroy the heat pipe.

1.5 Laser Soldering (LS)

Before discussing LS, perhaps some background information is in order. The word "LASER" is an acronym of "Light Amplification by Stimulated Emission of Radiation." Lasers can convert ordinary light of varying wavelengths into a monochromatic (single wavelength), coherent, collimated beam many times more intense than an atomic flash. Although focused laser beams can vaporize all known materials (Ref. 3), industrial lasers have proved to be safe when properly enclosed, operated and maintained.

Although pulsed YAG lasers have been available since about 1971, their use has been directed at cutting, drilling and welding, not soldering. The first laser soldering system with computer numerical control (CNC) entered the commercial market about 1976 as a 50 watt continuous wave (CW) CO2 flowing gas laser (Ref. 4), followed in 1982 by the CW YAG laser CNC soldering system.

There are a number of technical differences between laser types for soldering. As will be discussed later, CW lasers (CO2 or YAG) are preferred to pulsed lasers because soldering is a time-dependent process that is better served by means of a single lower power, steady pulse of laser energy than by a much higher peak power series of shorter duration pulses.

Laser soldering has a number of significant advantages not possessed by any other soldering method:
1. LS provides highly localized heating that will solder heat sensitive devices without damaging them because it does not heat the entire assembly, but only the immediate area being soldered.
2. LS forms shiny, ductile solder joints because the solder melts and solidifies so rapidly that appreciable IMC cannot form.
3. LS forms low-stress solder joints because the entire PWA is at room temperature, except for the momentary (1 second or less) solder fusion that forms each successive joint.
4. LS is applicable to heat sink assemblies, including those with heat pipes.

Figure 1 shows SMDs on a PWB bonded to a heat pipe, with another SMD/PWB assembly bonded to the back side of the heat pipe. A 304 pin connector is soldered along the bottom edge on both sides of the overall assembly, and a 96 pin connector is soldered along the top edge of both sides. There are 77 HCCs, 135 capacitors and resistors, 2 connectors and 2382 solder joints on the visible side of the 6-layer PWB shown. This engineering development model (white wires) was VPS prior to heat pipe bonding, after which connectors were hand soldered; however, SMDs could have been laser soldered after PWBs were bonded to the heat pipe.

In addition, LS eliminates formation of solder bridges and balls, thereby eliminating need for solder mask. LS can provide increased standoff distance between SMDs and PWB insulation because SMDs are not floated on molten solder. This increased standoff distance also allows for easier penetration of cleaning solvents beneath SMDs.

LS is essentially a non-contacting process that can reach whatever can be seen through the laser lens. Because of its focused nature and its ability to be precisely controlled by a computer, the 4-mil to 20-mil diameter (1 mil =0.001 inch) laser beam in conjunction with a CNC work positioner system, has demonstrated formation of acceptable solder joints on state-of-the-art PWA hardware.

LS does have some disadvantages: it forms solder joints individually, and requires accurate device orientation. In addition, LS is more capital intensive than WS or VPS; however, use of multiple beams is a means of increasing throughput to compete with other methods.

2.0 OBJECTIVES

Objectives of this laser soldering task were to determine laser characteristics and soldering feasibility of HCCs, connectors, and other SMDs.

2.1 Laser Characteristics

2.1.1 Safety

The YAG laser emits invisible light at a wavelength of 1.06 microns (1 micron = 0.001 millimeter = 39 millionths of an inch), which is readily transmitted by glass and most plastics yet absorbed by most metals. This wavelength will also damage the human eye retina.

The CO2 laser emits invisible light at a wavelength of 10.6 microns, which is readily reflected by most metals, yet will cut glass and plastics, and damage the human eye cornea. However, when properly enclosed, operated and maintained, lasers have proved to be safe to operate in a manufacturing assembly environment.

2.1.2. Reflection of Laser Beam Energy

Throughout the laser literature it was mentioned that the 1.06 micron wavelength energy from a YAG laser was better absorbed by metals than by other materials such as glass and plastics. Similarly, it was also mentioned that the 10.6 micron wavelength energy from a CO2 laser was better absorbed by glass and plastics than by metals. Because comparative data to support these observations was lacking, reflectance versus wavelength scans were made on unfused tin-lead plate and polyimide PWB insulation (after etch removal of copper cladding) at the Air Force Wright Aeronautical Laboratories (AFWAL), Dayton, Ohio.

The reflectance scans definitely substantiated prior observations. Figure 2 shows the scans obtained for YAG laser wavelengths. The tin-lead plate (SOLDER) showed a 21 percent reflectance, and the polyimide PWB insulation showed a 27 percent reflectance. This means that the insulation was a better reflector than the tin-lead, and would be less likely burned by YAG laser energy. Miller of U. S. Laser (Ref. 6) observed that discernible burning of polyimide insulation by a 20-mil diameter, 10-watt YAG laser beam moving at a rate of one inch per second (ips) could be prevented by a film of dried rosin flux.

Figure 3 shows scans obtained for CO2 laser wavelengths. Tin-lead plate showed a 74 percent reflectance, and polyimide PWB insulation showed about two (2) percent reflection. This means that insulation was a much better absorber than tin-lead, and would be more easily burned by CO2 laser energy than by YAG.

2.2 Laser Soldering - CO2 Laser

2.2.1 Solder Pastes and Fluxes

Solder paste was used during initial soldering attempts with pulsed YAG and CW CO2 lasers. Because no way was found to prevent formation of solder balls or to reliably remove them, use of solder paste was abandoned in favor of thick tin-lead PWB plate in conjunction with solder dipped SMD pads and externally applied type RMA flux. A CW CO2 system was used during process development because a YAG system was not then available.

It was observed that the CO2 laser would not melt solder once the initial film of rosin flux had been vaporized. According to Burns of Apollo Laser (Ref. 5), rosin absorbs 10.6 micron radiation and effectively couples this energy into solder.

2.2.2 HCC Soldering

Early in this task, it became apparent that as-dipped, leadless HCCs could not be readily soldered to PWB pads by means of a vertical laser beam because only three HCC pads would be in contact with PWB pads, similar to a tripod. Figure 4 illustrates a solder-dipped HCC pad that is not in contact with a PWB pad. In "A" of Figure 4, solder in the castellation remains unchanged by the laser beam because surface tension of molten solder prevents flow. Tipping the laser beam, as shown in "B", does not help because there is insufficient unfused tin-lead plate on the PWB pad to form the convex-shaped puddle of molten solder necessary to touch the hanging drop of molten solder on the HCC. In "C", however, two additional modifications have been made that will result in formation of acceptable solder joints: 1) flattening solder on HCC pads, and 2) using thick (1.2 - 1.8 mils), unfused tin-lead plate on PWB pads.

2.2.3 Flattening HCC Solder-dipped Pads

Adequate solder flattening was attained by applying flux to pads, placing the HCC on a black anodized aluminum plate, and reflowing the solder on a hot belt. Figure 5 is a SEM photograph of a HCC after solder dipping, and Figure 6 is a SEM photograph of the same HCC at a different angle after reflow flattening.

2.2.4 HCC Soldering

Figure 7 is a 30X SEM photograph of solder joints formed on an 18-pad HCC by means of a CO2 laser; each joint received eight watts power for 0.3 second (= 2.4 Joules). Figure 8 is a 200X SEM photograph of the second solder joint from the left in Figure 7. After shearing the HCC from the PWB with an applied load of 18 pounds for an average shear strength of one pound per pad, the pad of Figure 8 was rephotographed at 200X as shown in Figure 9. The direction of applied shear load was from left to right and parallel to PWB pads. Subsequent solder joints were much larger when laser soldered at 12 watts for 0.5 second (6 Joules), and required three pounds average per pad to shear.

Figure 9 also illustrates four features of laser soldering that were mentioned earlier:

1. LS provides highly localized heating. Note that solder on the 25-mil wide pad has fused about 5-mils onto the 10-mil wide conductor. Note also a raised, curved line of demarcation between fused and unfused tin-lead plate on the PWB pad to the left of the solder fillet. Formation of a raised surface during fusion is essential to HCC fillet formation.
2. LS forms ductile solder joints. Note the considerable displacement of solder; this illustrates the ductility of the solder fillet (compare with Figure 8) that results because the solder fuses and solidifies so rapidly that appreciable IMC cannot form.
3. LS is applicable to PWAs with heat pipes. Note that the highly localized heating demonstrated in 1 above also demonstrates solder fusion so rapid that solder joints are formed before heat penetrates to the heat pipe.
4. LS provides increased device standoff distance. The 4.4-mil standoff provided by this solder fillet allowed easier penetration of cleaning solvents. More important is the increased thermal cycling life that Fennimore of Martin Marietta Orlando Aerospace (Ref. 7) attributes to increased standoff distance.

2.2.5 Intermetallic Compound Formation

As mentioned earlier, less IMC is formed by LS than by other soldering methods because of rapid fusion and solidification of LS joints. Figure 10 shows a 1000X microsection of a laser soldered joint along with a microsection of a wave soldered joint by way of comparison. Copper-tin IMC is not discernible on the laser soldered joint, as compared with that seen on the wave soldered joint. Because IMC is formed by heat and time, the laser soldered section was obtained only by the use of extremely light grinding and polishing pressures while the specimen was kept immersed in coolant.

2.2.6 Connector Soldering - Solderability & Finish

Initial work was performed on curved MIL-C-55302/XXX contacts (Ref. 8). During this work it was determined that the laser beam did not weaken the copper-to-polyimide PWB adhesive bond. Figure 11 shows the CNC 20 watt CW flowing CO2 gas laser inside its eye-safe acrylic plastic enclosure.

Figure 12 is a SEM photo of a pad solder fillet whose contact had low peel test strength. Although the fillet is large, there are numerous voids, and very little evidence of torn solder. Figure 13 is a SEM photo of the contact. Circled areas were examined by EDX for tin-lead, nickel (underplate), and zinc (brass substrate). Analyses of Areas 2 and 3 are shown in Figures 14 and 15. The flat area shows a strong nickel peak, indicative of exposed nickel underplate. The rough area shows strong tin and lead peaks, indicative of tin-lead plate. The initial conclusion drawn from this data was that porosity in the 100 microinch thick tin-lead plate was allowing nickel oxidation, with subsequent dewetting of tin-lead during fusion.

Contacts with improved, thicker, unfused, bright acid tin-lead plate were obtained and successfully soldered with original laser parameters of 10 watts for 0.5 second. Figure 16 is a SEM/dot scan EDX for nickel on an improved contact after peel test. The white dots indicate exposed nickel; compared with Figure 15, there is much less exposed nickel on the improved contact. Porosity of the fused and torn tin-lead plate (now solder) was initially attributed to inadequate flux drying. Figure 17 shows the nickel dot scan alone.

Additional unfused, bright acid tin-lead plated contacts were laser soldered to a PWB; some of these contacts were laser soldered at 18 watts for 1 second (18 Joules) and the rest at 24 watts for 1 second (24 Joules). The inspection data was revealing: although the solder fillets were visually acceptable, 90 percent (35 out of 39) of the 18 watt joints fractured with less than 3 grams of lifting force applied at the toe of the contact.. In contrast, only 32 percent (12 out of 38) of the 24 watt joints fractured when tested as before, an indication that greater energy input was somehow effective in increasing joint strength.

At about this point in time, a literature search revealed a number of articles that attributed low joint strength to the use of bright acid tin plate on leads. According to DeVore of GE (Ref. 9), co-deposited organic brighteners in the plate are decomposed at soldering temperatures, forming gases that oxidize the nickel underplate, causing dewetting, and also creating porous solder joints. Because hand tinned contacts and/or higher energy (24 Joules) laser soldering produced higher peel strength test joints, it would appear that improved adhesion is related to the increased time and heat available for these gases to escape.

2.2.7 Connector Soldering - Importance of Defining Contact Configuration

Figure 18 shows a 185X cross section of a prototype 3-mil by 16-mil copper contact after laser soldering at 12 watts for 0.4 second (4.8 Joules). Figure 19 is a 185X cross section of a 10-mil by 20 mil contact that required 22 watts for 1 second (22 Joules), nearly five times more power than for the smaller contact. More serious, however, was insulation burns between PWB pads by reflected energy off of angled contact edges.

2.3 Laser Soldering - YAG Laser

Although initial laser soldering evaluation was performed on YAG and CO2 lasers, most work up to this point had been performed on an inhouse CO2 laser. To evaluate a CW YAG laser and further test DeVore's theory concerning unfused, bright acid tin plate, another connector was repeatedly fluxed with acid flux and fused until all outgassing had ceased and each contact had been solder wetted.

After being coated with RMA flux, and contacts were CO2 laser soldered to the PWB to maintain contact alignment, and then sent to be soldered at various power levels and time durations by a CW YAG laser soldering system manufacturer.

All solder joints were then inspected at Martin Marietta Orlando Aerospace and individually logged for visual defects, SEM photographed, and then pull strength tested at 4-ips on a Unitek Model 6-092-03 pull tester. The test data obtained was statistically analyzed and summarized as shown in Table I in decreasing order of pull test strength.

According to Table I, there is good correlation between the "QA Visual" and "Avg. Pull Strength" data. Comparison of "Power X Dwell" and "Joules" with "Avg. Pull Strength" for the five groups clearly shows that Group A, although visually and statistically the best group, did not receive the most power, longest dwell, or most energy.

Data of Table I supports prior laser soldering data showing that stronger and better looking solder joints are obtained on fused, well tinned surfaces than on unfused, bright acid tin plate.

Table I data also shows that optimum power/dwell parameters must be developed for each termination configuration.

Figures 20 and 21 are SEM photographs of Group A terminations No. 1-2-27 and 1-2-28 which had the the strongest solder joints in the group (2870 grams/6.3 pounds and 3100 grams/6.8 pounds respectively). Figure 22 "A" is a SEM photograph of termination 1-2-27 after pull test. The rough