Soldering microelectronic assemblies: some problems and studies

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Abstract

In the application of SMT, the provision of highly solderable surfaces on component terminations and circuit boards is still a primary requirement for reliability. Checking of solderability of components is desirable but methods for this have not been perfected because of the small size of components. Visual inspection is becoming extremely difficult, if not impossible, and reliance must therefore be placed on using surfaces of good solderability and close control of the soldering processes.

KEY WORDS: Micro-electronics, SMT, Solderable Surfaces, solderability testing, inspection.

1. Introduction

The radio and electronics industry is less than one hundred years old and even in that short period of time there have been dramatic changes in the technology and it is useful to review these changes. For instance, point-to-point wiring was the interconnection technique until about forty years ago when Eisler developed the concept of printed wiring boards on which the components were mounted, utilising the long-established expertise of the printing industry. From that time we have seen single-sided circuits replaced by double-sided, first with through interconnecting pins and later with plated through holes. Multilayer boards then entered the field together with flexible circuits and flexible printed wiring harnesses. In parallel with these developments in printed wiring board technology, microcircuits came into being which could effectively form one or more electronic components having specific and complex functions which were mounted on the rigid mother circuit board. In thick-film microcircuits, again printed technology was generally used for form the conducting tracks on, for example, an alumina substrate, the "inks" containing metallic powder mixes which were subsequently fired to form a bond to the alumina. In thin-film microcircuits, another widely used high technology was made use of, namely chemical vapour deposition or sputtering. It is the international race to make a more cost-effective use of space that has led to the recent rapid application of microcircuit technology to the majority of components both passive and active, whose size prohibits the use of normal wire terminations on components, soldered into through holes. Thus, surface mounted devices are being used increasingly enabling high packing density of components on a single- or double-sided "mother" circuit board. The competitiveness of SMT is seen in the concentration of papers in the technical process on this subject together with seminars and conferences devoted to SMT. However, it is as well to place this relatively new development in its real perspective.

Data relating to the industry in Japan (ref. 1) shows that on average, SMT will reach 50% utilisation in the electronics industry only by 1990. Specifically, passive surface mounted devices are predicted to be increasingly used in consumer and industrial electronic equipments by 1991 and, for example, nearly full use is already made of SMD's in video equipment and electronic cameras but in television, usage will increase from 4% of components to 29% and in communications equipment from 28% to 68% in that period.

There are in any electronics assembly many more soldered joints than there are components so it is essential that each of these is of a quality to ensure long lasting performance, both to provide an electrical connection and usually to attach the component to the mother board. Therefore, it is essential that perfect soldered joints may be made quickly and easily on the production line. This requirement has always applied to the printed circuit board and to the component terminations and all that has changed is the greatly reduced size of the joint to SMD's. Most problems connected with the soldering process are associated either with the ease with which solder wets the surfaces, that is, solderability of board or component, or with mechanical factors arising during processes such as wave soldering. Production requirements and deadlines often lead to insufficient attention being paid to details of the soldering processes or earlier processes and this is seen in the tendency for a decreasing yield of acceptable products as the complexity of the item increases.

The main purpose of this paper is to highlight some of the difficulties in achieving high integrity soldered joints to SMD's, the reasons for them and to discuss the possible means of overcoming the problems.

Solderability of Surfaces

All metallic surfaces exhibit different levels of wettability towards molten solder which in general is related to the propensity for the metal to oxidize and also to the inherent metallurgical reaction rate ie. liquid-solid diffusion, with liquid solder. Solderability of a surface may be indicated by the acidity or activity of the flux required to remove the oxide film and enable wetting to proceed; however, fluxes of very low activity, usually based on rosin, are frequently specified for electronics assembly work, which are capable virtually only of maintaining oxide free surfaces on substrate and solder and therefore require all surfaces to be soldered to have only minimal oxide films present. Extensive work or printed circuit board materials at the ITRI (ref. 2) showed that to meet the requirements of being easily solderable with a rosin flux even after prolonged exposure to elevated temperature/high humidity conditions, coatings of 5-8μm thickness of pure tin or 60% tin-40% lead alloy should be used. This is the basis of National and International Specifications (ref. 3). It is essential that the basis metal (often copper) should be absolutely free of contamination before these coatings are applied since during soldering the coating is dissolved or melted away and the solder is then in direct contact with the basis metal. Incorrect preparation of the underlying copper leads to dewetting of solder on printed circuit laminate after wave soldering: copper cleaned with a rotating buffing wheel loaded with 1μm alumina, to give a visually excellent finish on the copper, causes the alumina particles to embed in the copper resulted in wetting problems. (ref. 4) Electroplated tin or tin-lead alloy coatings on printed circuit boards may be reflowed after plating and if no evidence of dewetting of the brightened coating is seen, it can be assumed that solderability will be good. Likewise, coatings applied by the solder dip and air wipe technique can be assumed to have properly wetted the basis copper if no wetting defects are observed. Most printed circuit boards used today make use of a 5µm minimum thickness of 60/40 tin-lead alloy coating and rarely present soldering problems.

With regard to components, the problem is more complex because the surfaces to be soldered may be subjected to a variety of processing treatments during the manufacturing stages and it is sometimes unacceptable to apply the required tin or tin lead coating to the terminations as a final process. A small number of manufacturers do indeed solder dip termination wires etc. as a final process but the difficulty of mechanizing this and of removing residues of flux used in the dipping process is large.

For various reasons surface finishes other than tin or tin-lead alloy may need to be used and moreover the substrate may not be in the form of a smooth, fabricated metal such as copper foil or wire. An example is seen in the wide use of precious metal based, fired, metallised layers on alumina for chip resistors. These metallised layers allow rapid metallurgical reaction to occur during soldering, during burn-in treatment or in elevated temperature service, which may lead to the formation of thick intermetallic compound layers and the possibility of brittle soldered joints. Complete conversion of the metallised layer to intermetallic compound also means that the compound would be in direct contact with the underlying alumina and may no longer be bonded to it. This problem is magnified by the relatively high roughness and porosity of the alumina surface so that even with a metallised layer such a copper which does not react abnormally fast with solder, intermetallic compound may form which penetrates through the copper to the underlying alumina, which may reduce bond strength. (ref. 5) In the higher quality components, the initially fired metallised layer is subsequently coated with a thick layer of nickel, which has a low rate of reaction with solder and the thickness of the layer eliminates complete conversion of the metal layers to intermetallic compound. Provided that the nickel is then tin or tin-lead alloy coated it will be quite solderable but if left unprotected, nickel has a rather poor solderability and requires the use of a quite active flux during soldering.

Even when adequate precautions have been taken to provide surfaces which will always exhibit excellent solderability it is necessary to ensure that they have adequate solderability after storage, because some delay in usage of components before assembly is inevitable.

On conventional electronic components, the wetting balance has become widely used to check the solderability of wire or spade terminations; the method is the subject of an International Specification (ref. 6). In this method, the force acting on the test-piece immersed in solder is monitored as a function of time: the time for the upward buoyancy force acting on the specimen to be equalled by the downward wetting force is taken as a measure of solderability or more simply the time for the force to cross the zero-force axis, which is a slightly higher value, is taken. However, when testing passive SMD's, the basis material may be alumina and the wetting forces acting on the metallised connection pads are small because of their small size, with the result that the buoyancy forces more than counteracts the changes in wetting force. This was illustrated by work at ITRI: (ref. 7) to round copper wires a solder resist coating was applied to leave various lengths of exposed copper at the end of the wire; these were tested in a wetting balance and the results obtained indicated that the force-time curve obtained is seriously affected by the solder resist inhibiting meniscus rise of the solder up the wire. Thus chip components which often have metallised lengths of only about 1mm. could not be tested for solderability by the standardised technique.

Subsequent work has led to the replacement of the solder bath by a solder globule which the component contacts. Although interpretation of the physical aspects of this test are complex, the nature of the curved surface of the solder reduces the surface tension forces causing vertical meniscus rise so that the inhibiting effect of the small exposed metallised length on the component, discussed above, is more or less overcome. This new technique is the subject of a new draft standard proposed to be included within IEC 68-2-20 and "round-robin" testing is still needed to establish the validity and usefulness of the test method.

Soldering Process Problems

Reflow soldering of SMD's to circuit boards is an established procedure, manufacturers seeming to be divided between the use of infra-red heating and vapour-phase (condensation) soldering. These processes require the use of carefully formulated solder creams (ref. 8) to avoid solder-balling and spattering and to enable accurate location by screen-printing, pin transfer or syringe of the cream in the required positions, without any spreading or slumping before or during drying. There is vigorous competition amongst the solder cream suppliers and generally 63% tin-37%lead, 60%tin-40%lead or 62%tin-36%lead-2%silver alloys are used. The latter is often recommended not only for its greater strength but also for its supposed reduction in rate of dissolution of silver-containing metallised layers. However, in laboratory experiments with vapour phase soldering of silver-palladium metallised layers, there were no significant differences in initial thickness of intermetallic formed during soldering, nor in compound growth rate during heat treatment between the solder creams with or without the presence of silver. (ref. 9)

A design feature affecting reflow soldering of components is the influence of pad size. There are recommendations for preferred sizes and pads which are significantly larger than the component metallised area often leads to twisting of the component as surface tension forces act on it. Wherever possible therefore, pad width should not exceed component width but clearly there must be sufficient overlap at the extremites to allow an adequate solder fillet to form. Another important aspect of reflow soldering is to ensure uniform and good solderability of all surfaces otherwise "tombstoning" may result due to the uneven surface tension forces acting on each end of the component. This defect can also arise from non-uniform heating by the infra-red method so that solder melts fully at one end first and surface tension forces pull the component on end.

Regarding the number of metallised faces or chip components, the presence of a soldered joint beneath the component (4 or 5 sided metallisation) provides a joint of much higher shear strength.

For SMD's adhesively attached to the "solder side" of a printed circuit assembly and subsequently wave soldered, very close packing can result in inadequate penetration of the solder wave into the small gaps to give rise to "solder skips". Thus good design of the assembly can be a critical factor and the choice of the type of solder wave also is important: turbulent rather than smooth-flowing solder waves encourages penetration of the solder into all small gaps.

Wave soldering also can lead to capillary penetration of flux beneath components which is extremely difficult to remove in the cleaning process after soldering. Clearance beneath the components can be provided by using stand-offs and this aids flux removal but high pressure jet cleaning with solvents and other advanced methods are being used experimentally to overcome the problem of flux entrapment beneath components, (ref. 10) since use of ultrasonics may damage components.

An ancillary problem is that wave soldering has always led to oxidation and dross formation on the solder bath which if not removed may be circulated within the wave of solder and thus entrapped in the soldered joints. Machine design has improved which reduces this possibility but dross still represents an operating financial loss to the manufacturer. Recent experimental work has demonstrated that traces of all elements increase dross formation with the exceptions of phosphorus (and perhaps sulphur). (ref. 11) High purity solders would therefore seem to be preferred perhaps with up to 0.001% phospherus present but this element is lost with time and strict control on further additions would be necessary to maintain the effect of reduced drossing.

Quality Inspection

With conventional wire-ended components mounted in through holes on circuit boards, there are few actual difficulties in carrying out visual inspection of the soldered joints. The basis of inspection is to compare the appearance of the joint against set standards and the ITRI Visual Aid Slide Sets have been widely distributed to assist in training inspectors or used as colour prints to act as a guide at the inspection bench. (ref.12) These picturers show typical perfect joints together with wetting and other soldering defects. For example, incomplete solder fillet formation may constitute a defect, if so specified. Magnifying lenses of powers up to 5 times are frequently used to help with the smaller dimension circuitry.

In the case of SMT, components may be so small that magnifications up to 50 times may have to be used in extreme cases. Furthermore, the far greater number of mounted components means that only a much smaller proportionate sample of joints may be selected and also the close packing may physically obscure some of the joints. New visual aids are slowly becoming available and some of these are available from ITRI and within individual companies. New questions have to be asked such as "is a bulbous solder fillet to one end of a chip component acceptable or is the traditional fillet showing low contact angles still preferred?" Many believe that the large fillet provides a greatly increased resistance to fatigue cracking under conditions of thermal cycling. Legson leaded chip components may not all be firmly in contact with their pads before soldering or may be partly off the pad due to twisting of the LCC during reflow soldering. It has also been observed that frequently after infra-red reflow soldering, the solder surface in the joints is dull and yet traditionally, all soldered joints should have a bright, smooth, reflective appearance to be acceptable. The explanation of these dull joints seems to be associated with the quite slow rate of cooling after reflow soldering which allows relatively coarse dendrites of lead-rich phase to protrude at the surface of the solder, to produce a micro-roughness, and therefore is considered not be detrimental to quality of the joint.

In view of the new requirements for joint inspection and the practical problems involved, alternative methods of checking joint quality are being sought. Total electrical testing will, of course, ensure complete electrical continuity at the time but it is well known that purely mechanical contact would give such a result for a short period. The use of a laser to obtain a "thermal fingerprint" of the joint has been developed (ref. 13) and is still being improved to deal with microcircuits. Similarly, use of scanning X-ray shadowgraphs is being studied. Ultimately it may be that reliance on correct design and production engineering control schedules will become intensified (ref. 14) and any assemblies that fail electrical testing will be rejected and perhaps not even repaired due to cost implications. Indeed, this is an existing practice in a few specific instances.

Summary

Quality assurance as applied to surface mount technology entails a dedication to applying the correct designs, specifications of materials and processes and their control on the production line. A vast amount of technical information is already available which should allow this to be carried out but it is necessary that all of the personnel involved realise the importance of the metallurgical factors involved in obtaining soldered joints of high integrity. Adequate education and communication between technical personnel is an essential feature of establishing the production of high quality joints as a regular routine.

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