Wave Soldering: Is S.O.I.C. Reliability Compromised?

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Jim Walker
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INTRODUCTION

Surface mount devices can be attached to the printed circuit board using a variety of processes, both new and existing. Vapor phase reflow and wave soldering are two such methods. These procedures allow surface mount semiconductors to be attached to one or both sides of the printed circuit board. The assembly options can be divided into three categories for integrated circuit considerations.

1) Components are subjected to a vapor phase reflow cycle followed by a wave solder heat cycle, or the process is reversed.
2) Components are subjected to only a vapor phase heat cycle.
3) Components are subjected to wave soldering only and are exposed to heat by immersion into the molten solder.

Of these three processes, the last subjects the I.C. to the most severe heat treatment. This is a reliability concern which will be explored in the following discussion.

THERMAL CHARACTERISTICS OF PLASTIC INTEGRATED CIRCUITS

The die within plastic dual-in-line packages (DIPs) and surface mount devices (SMDs) is encapsulated with a thermosetting epoxy. The thermal characteristics of the epoxy can be analyzed by Thermal Analysis; primarily Thermomechanical Analysis (TMA). The critical properties of the plastic epoxy are: (a) its linear thermal expansion and (b) its glass transition temperature. A typical TMA graph is illustrated in *Figure 1*. Notice that the expansion rate (designated as α) of the epoxy increases by a factor of 3 when the glass transition (Tg) is exceeded. In contrast, metals (as used on lead frames) generally have a constant linear thermal expansion over the same temperature range.

In any good reliable plastic package, the choice of lead frame material should be such that it closely matches the expansion of the epoxy encapsulant. Most operating conditions of a device are kept at temperatures below the glass transition. In this situation the possibility of separation at the epoxy-metal interface is minimal. However, as the package is subjected to temperatures above its glass transition, the epoxy will begin to expand much faster than the metal. In the event that there is this mismatch between the two, a stress can build up at the interface, causing the epoxy to separate from the enclosed lead frame.

WAVE SOLDERING

One of the benefits of surface mount technology is that devices can be mounted to both top and bottom sides of the printed circuit board. During wave soldering, components on the underneath side are actually immersed into the hot molten solder. The plastic-metal interface can be affected if left for more than 5 seconds.

Most wave soldering operations occur at temperatures between 240°C to 260°C. Epoxies used for semiconductor encapsulation have glass transition temperatures between 140°C to 170°C. An integrated circuit exposed to these temperatures can risk long term functionality and reliability. However, with top side mounting (as used for DIPs) there are some factors that reduce the risk.

1) Only the tips of the leads are exposed to the solder temperature.
2) The printed circuit board acts as a heat sink and also shields the components from the temperature of the solder. Actual measurements on DIPs show that they are exposed to a temperature between 120°C–150°C in a 5 second pass through the solder wave. This accounts for the fact that packages mounted in the conventional manner (top side only) are very reliable.

PACKAGE PERFORMANCE

Wave soldering requires the use of fluxes to assist solderability of the components to the circuit board. In some instances, the boards and components are processed through acid cleaning prior to passing through the wave. If epoxy-metal separation has occurred, the flux and acid resi-

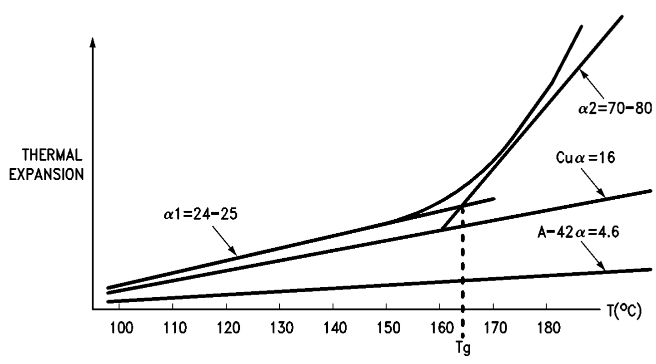

FIGURE 1. Thermal Expansion and Glass Transition Temperature: (Tg)

dues (which may be present due to inadequate cleaning) will be forced into the separation mainly by capillary action as they move away from the solder heat source. Once the package is cooled, these contaminants are now trapped inside the package and are able to diffuse with available moisture over time. It should be stressed that electrical tests performed immediately after soldering generally will give no indication of this potential problem. As time passes however, the end result will be corrosion of the chip metallization and premature failure of the device in the field.

TEST CONDITIONS

Of all the environmental stress tests which can be performed on integrated circuits, the most revealing is the ‘‘bias moisture’’ test. In this test, the I.C. packages are pressurized in a steam chamber to accelerate penetration of moisture into the package. An electrical bias is applied on the device. Should there be any contaminants trapped within the package, the moisture will quickly form an electrolyte and cause the electrodes (lead fingers), the bonding wire and the aluminum bond pads of the silicon device to corrode. Usually the aluminum bond pads are the weakest link in the system and are the first to fail. Typical environmental conditions for a bias moisture test are 85% relative humidity and 85°C.

RELIABILITY RESULTS—THE SMALL OUTLINE PACKAGE

Comparision of vapor phase and wave soldering upon the reliability of molded Small Outline packages was performed using the bias moisture test (Table I). It is clearly seen that vapor phase reflow soldering yields more consistent results. Wave soldering gave results that, although not corresponding to a production environment, signify the need for absolute control of the soldering parameters; specifically temperature and duration.

TABLE I. Vapor Phase vs. Wave Solder: S.O.I.C.

Solder Method
1. Vapor phase (60 sec. exposure @ 215°C) = 9 failures/1723 samples = 0.5% (average over 32 sample lots)
2. Wave solder (2 sec total immersion @ 260°C) = 16 failures/1201 samples = 1.3% (average over 27 sample lots)

Package: SO-14 Lead, board mounted
Test: Bias moisture test, 85% R.H., 85°C for 2000 hours
Device: LM 324M

In Table II, the tolerance of the S.O.I.C. package to immersion time into a hot solder pot is examined. In the first test, the results indicate that, after more than 3 seconds exposure, a significant number of failures occur. This is not unexpected as the package is very small in size and therefore experiences a rapid temperature rise (thermal shock) followed by stresses created by the mismatch in expansion.

TABLE II. Wave Solder Immersion Summary (85% R.H. /85°C Bias Moisture Test, 2000 hours)

Immersion Time	Failure Rate
1–3 seconds	2/144 (1.4%)
4–6 seconds	13/248 (5.2%)
7–9 seconds	14/127 (11.0%)

Package: SO-14 Lead, not mounted to circuit board
Device: LM 324M
Solder Temperature: 260°C

The packages were mounted on a printed circuit board for the results in Table III. The presence of the board seemed to minimize the effect of severe temperature excursion. Based upon these results, it is possible for Small Outline packages to undergo a wave soldering operation by direct immersion provided the duration of immersion does not exceed 4 seconds. As stated previously, unless the control of the soldering environment is absolutely rigid, there is a chance for manufacturing unreliable assemblies. The recommendation is to restrict the immersion time to 3 seconds to minimize failures due to wave soldering.

Finally, Table IV compares the performance of surface mount components manufactured by various semiconductor manufacturers. This reveals that a manufacturer’s package design criteria, materials, and processing critically determine the reliability of the Small Outline package.

CONCLUSION

The vapor phase reflow method of soldering the small outline package is highly reliable. Wave soldering can prove detrimental if the process controls (thermal and time limitations) are not closely monitored.

TABLE III. Wave Solder Results—S.O. Package Circuit Board Mounted

Immersion Time in 260°C Wave Solder	Bias Moisture Test (85% R.H./85°C)		
	(2000 hr)	(4000 hr)	(6000 hr)
2 seconds	0/55	0/55	0/55
4 seconds	0/54	0/54	0/54
6 seconds	0/47	1/47	3/46
8 seconds	3/17	—	—

Package: SO-14 Lead, board mounted
Device: LM 324M

TABLE IV. U.S. Manufacturers Integrated Circuits Reliability in Various Solder Environments

Test Group	Condition (A): Vapor Phase Reflow Solder			
	2000 hr	**4000 hr**	**6000 hr**	**8000 hr**
A	0/80 0/78	1/80 1/78	0/79 0/77	0/79 0/77
B	7/60 8/58	. . . . . . discontinued . . . . . . discontinued		
C	7/30	3/23	0/20	0/20
D	0/30	0/30	0/30	0/30

Device: LM 324
Package: SO-14 Lead
Test: Bias moisture test, 85% R.H./85°C

Condition (B): Wave Solder (Non-Halide Flux, 4 Passes @ 260°C)				
Test Group	**Cycle Time**			
	2 Sec	**4 Sec**	**6 Sec**	**8 Sec**
A	1/68	1/59	1/56	0/58
C	11/30	30/30	14/30	30/30
D	0.30	0/30	2/28	7/30

Test: 2000 hours Bias moisture test @ 85% R.H./85°C
Device: LM 324
Package: SO-14 Lead

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National Semiconductor Corporation
1111 West Bardin Road
Arlington, TX 76017
Tel: 1(800) 272-9959
Fax: 1(800) 737-7018

National Semiconductor Europe
Fax: (+49) 0-180-530 85 86
Email: cnjwge@tevm2.nsc.com
Deutsch Tel: (+49) 0-180-530 85 85
English Tel: (+49) 0-180-532 78 32
Français Tel: (+49) 0-180-532 93 58
Italiano Tel: (+49) 0-180-534 16 80

National Semiconductor Hong Kong Ltd.
13th Floor, Straight Block,
Ocean Centre, 5 Canton Rd.
Tsimshatsui, Kowloon
Hong Kong
Tel: (852) 2737-1600
Fax: (852) 2736-9960

National Semiconductor Japan Ltd.
Tel: 81-043-299-2309
Fax: 81-043-299-2408