SAND2011-0765C

Proceedings of the ASME 2011 Pacific Rim Technical Conference & Exposition on Packaging and Integration of Electronic and Photonic Systems
InterPACK2011
July 6-8, 2011, Portland, Oregon, USA

InterPACK2011-52289

A PRACTICAL APPROACH FOR LOW-COST HERMETIC LID SEALING

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ABSTRACT

Hermetic sealing of lids in ceramic microelectronic chip carriers is typically performed with eutectic solder in relatively large belt-style reflow furnaces. This process is characterized by 30 to 45-minute cycle times at temperatures above 350 C. An experimental study was undertaken with the goal of establishing a low-cost lid sealing method marked by a compact belt furnace with lower reflow temperature and lesser cycle time. This is particularly advantageous for GaAs devices which are limited to packaging process temperatures below 300 C. A series of instrumented test samples consisting of a representative die packaged in a HTCC leadless chip carrier (LCC) was prepared. Package lids were installed and sealed in a nitrogen environment with 80-20 Au-Sn lead-free solder under various cycle time and temperature conditions. Gross and fine leak testing confirmed hermeticity. Results indicate that practical sealing can be realized in the compact furnace apparatus with measurable reductions in temperature and cycle time. Seal performance is dependent upon package orientation, which suggests the process must be calibrated for unique package designs. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under Contract DE-AC04-94AL85000.

INTRODUCTION

Application-specific integrated circuits (ASICs) configured for High-Reliability microelectronic systems commonly feature hermetically-sealed high-temperature co-fired ceramic (HTCC) chip carriers. It follows that to achieve consistent hermetic sealing, packaging engineers rely on multi-stage belt or conveyor–style reflow ovens[1]. Energy consumption and cycle time of this equipment may unnecessarily inflate manufacturing cost and throughput. In 2006, Kaênica measured energy consumption in a convection oven, thereby optimizing efficiency of the reflow step in a printed circuit board (PCB) assembly[2]. This work extends the theme to hermetic sealing of HTCC leadless chip carriers (LCCs). The lack of availability of an earlier generation large-frame reflow oven presented an opportunity to conduct a practical experimental program that aims to perform the process at lower zone temperatures and lesser cycle time in a compact dual-mode conduction/convection reflow oven. The results are reported here.

NOMENCLATURE

ASIC application-specific integrated circuit
HTCC high-temperature co-fired ceramic
LCC leadless chip carrier
GaAs gallium arsenide

Figure 1 is a basic reflow process schematic[1]. For hermetic lid sealing in this study, multiple 16-pin LCCs are oriented horizontally and arranged in parallel on a stainless steel or similar metal block (6.4 x 8.9 cm, 0.76 cm thick). Metal clips hold an Au-plated A42 lid with 80-20 Au-Sn solder pre-form against the package frame. The assembly is configured with the lid facing downward for greater conduction to the pre-form. A sweeper bar attached to a conveyor pushes the steel block and package/clip assemblies along a series of heated platens (see Figure 1) which conduct heat to the pre-form. Modern reflow ovens also provide engineering controls of parameters that are crucial to favorable solder wetting and fillet formation. As

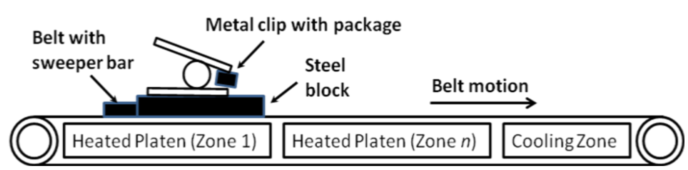


Figure 1 Hermetic sealing reflow process schematic.

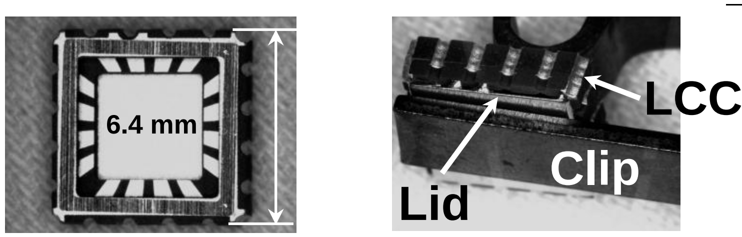
Tummala and Rymaszewski relate, the key parameters include conveyor velocity, peak temperature, local relative humidity, and atmospheric composition[3]. To optimize the time-temperature relationship, the series of platens shown in Figure 1 are independently heated or cooled to form zones of programmed steady-state temperature. The TSJ3-3-40N60 belt-style reflow oven (BTU International) with which the original hermetic sealing reflow process was performed, contains three such zones. Process parameters are listed in Table 1. Inspecting the table reveals the process cycle time and size of the equipment, and hence the motivation for the present study: measurable savings in cycle time may be realized in a reflow system with multiple heat transfer modes, higher density of zones, and therefore greater heat flux to the package in comparable time.

Table 1 TSJ3 Process Parameters

Parameter	Value	Units
Conveyor length	4	m
Conveyor velocity	1.43	mm/s
Cycle time	46	minutes
Zone 1 temperature	255	ºC
Zone 2 temperature	260	ºC
Zone 3 temperature	400	ºC
Peak temperature at LCC interface	310	ºC

EXPERIMENT

Figure 2a depicts the LCC with lid removed and Au-Sn pre-form exposed, while Figure 2b is a photo of the LCC mounted lid-down in the clip. Three LCCs with pre-forms, lids, and metal clips were arranged in parallel and affixed with Kapton® tape to a stainless steel block in a manner similar to Figure 1. LCCs were plasma cleaned prior to reflow. A pair of thermocouples was placed on each assembly, one at the package lid, and one on the body of the clip. Each assembly was run through a compact, dual-mode reflow oven (Sikama Falcon 5C). The Sikama apparatus includes a 1.2-meter long conveyor with four programmable conduction heating zones and four programmable convection heating zones directly above. Each zone is 12.7 cm wide and 14 cm long. Two cooling stages follow the conduction zones and one cooling stage follows the convection zones (see Figure 1). Convection heating zones include nozzles that flow heated nitrogen at a nominal rate of 40 standard cubic feet per hour. The gap between the conductive platens and convection nozzles is variable with a nominal height of 2.5 cm.



(a) (b)

Figure 2 (a) LCC with lid removed, (b) LCC mounted in clip, lid down.

Seven process trials (three parallel LCC samples per trial) were executed with selected zone temperatures and conveyor velocities. A temperature history for each run was compiled from thermocouple data. Sealed packages underwent visual and x-ray inspection of the seal area, followed by fine and gross leak tests. Test results identified the reflow recipe that yields the prescribed peak temperature profile (greater than 280ºC for a maximum of five minutes with peak temperature limited to 320ºC), a structurally-sound hermetic lid seal, and the lowest cycle time[4].

RESULTS

Table 2 is a summary of experimental parameters. Cycle time and peak temperature results for each trial are listed below.

Table 2 Experimental Parameters

Trial	**Conduction Zone Temps** (ºC)	**Convection Zone Temps** (ºC)	**Conveyor Velocity (mm/s)**
1	200-280-375-375	175-245-320-332	2.96
2	200-280-375-375	175-245-320-332	2.54
3	200-280-360-360	175-245-320-332	2.54
4	200-280-350-350	175-245-320-332	2.54
5	200-280-340-340	175-245-300-315	2.12
6	200-280-340-340	175-245-300-315	2.54
7	200-280-340-340	200-230-340-340	2.12

Table 3 Results

Trial	**Cycle Time (min: sec)**	**Peak Temp at LCC Lid (ºC)**
1	6:08	298
2	6:53	335
3	6:59	325
4	**7:15**	**320**
5	8:39	320
6	6:59	315
7	8:45	330

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Of the seven runs, Run 4 achieved the prescribed temperature profile with the least cycle time. The corresponding temperature history at the lid interface is shown in Figure 1Figure 3, below. Results revealed the process is sensitive to the orientation of the LCC. The intuitive lid-down configuration, with the seal closest to the oven's conductive surfaces yielded the desired temperature history. Figure 4 is an X-ray image of a typical lid sealed by the preferred process. The X-ray shows a uniform seal, free of (discolored) voids. Ten samples were subjected to fine and gross leak tests per MIL-STD-883G, Method 1014.2. The procedure consists of infiltrating the die cavity with helium and subsequently measuring the rate of gas escaping from the pressurized volume. Leak rates must not exceed 9 x 10^{-8} atm-cm^3/s after 60 seconds. The greatest leak rate observed was 1.3 x 10^{-9} atm-cm^3/s.

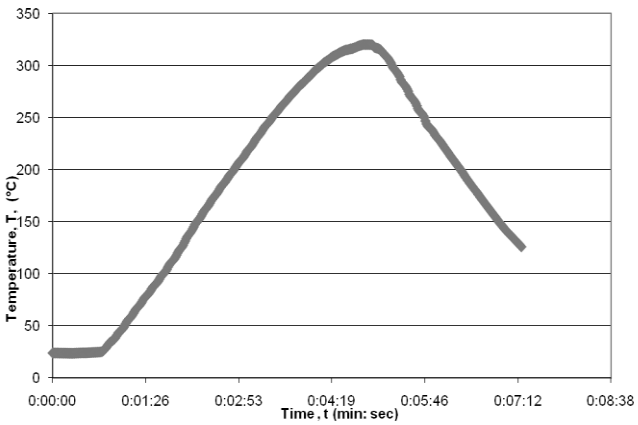

Figure 3 Temperature history: Run 4.

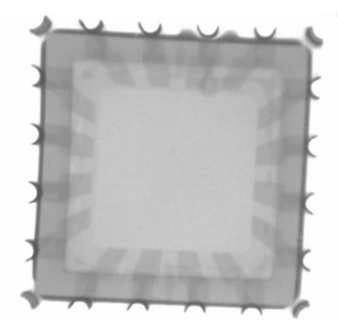

Figure 4 Post-lid seal X-ray image.

DISCUSSION

From the results, it is clear that hermetic lid sealing in this example is possible with the compact, dual-mode conduction/convection reflow oven in a fraction of the cycle time relative to the larger apparatus assuming the recommended lid/seal ring design guidelines are observed[4]. Moreover, zone temperatures did not exceed 350ºC, whereas 400ºC was required previously. Lower process temperatures are of interest in future investigations of lid sealing in GaAs devices, which are limited to packaging temperatures below 300ºC. At higher temperatures, GaAs devices are subject to so-called sinking gates, whereby gate metal interdiffusion into the channel and electromigration of Au metalization accelerates[5]. Important to note is that in this context, cost savings is realized through relatively low capital investment (roughly $25k), reduced cycle time, greater product throughput, and lower labor costs and not necessarily energy savings. Here, cycle time reduction comes at the expense of power input to the system. To illustrate this argument, we consider the time rate of change of thermal energy q in the package during the process shown in Figure 3, where ρ

$$\dot{q} = \rho c V \frac{dT}{dt} \qquad (1)$$

is the package mass density, V is the volume, and c is the specific heat[6]. Comparing the profile of Figure 3 to the profile described in Table 1, it is clear that the slope of the plot, dT/dt, is greater and as such, Equation 1 suggests that the change of thermal energy, and therefore the power input by the oven controller, is correspondingly greater.

CONCLUSIONS AND FUTURE WORK

An experimental investigation was conducted that validated a hermetic lid seal process for a HTCC LCC using a compact, dual-mode conduction/convection reflow oven. Hermetic seals were achieved in a fraction of the cycle time relative to a larger apparatus. These results suggest that savings in variable labor costs and greater product throughput are possible with use of this system but may not be achievable for all lid/package combinations. Future work will quantify energy use in the process.

ACKNOWLEDGMENTS

The authors thank J. J. Mulhall and Benjamin Thurston for their contributions to this work.

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