Achieving Low Voiding with Lead Free Solder Paste for Power Devices

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Abstract

The objective of this research was: (1) to demonstrate a low void concentration of <5% using solder paste on different materials such as nickel to nickel, copper to copper, nickel to copper, and with silicon die to nickel and silicon die to copper; (2) to achieve a short cycle time for the solder paste reflow operation and (3) to highlight the advantages of solder paste vs. AuSn and other alloy preforms that require gold top metallization.

For power device applications where low void concentration and reduced costs are important, we have demonstrated a solder paste solution that can be a lower cost solution. The flux process for solder paste is a major contributor in creating voids. Our approach was to utilize different pressures to reduce voids resulting in higher production yields.

Test coupons of pure nickel and copper were sized to simulate die and substrates. Silicon device die were also included. A lead free 95Sn5Ag alloy water soluble solder paste was selected for this evaluation. The paste application consisted of a manual screen print with templates of different thicknesses. Void detection concentrations were identified via our in-house X-ray system. The advantages of solder paste can be significant, but typically, we'd expect increase in voids resulted from the flux incorporated in the paste. Accordingly, in this paper, we evaluated a low voiding flux solder paste compatible with power device metal materials and suitable for use in a production environment.

Background

High power devices operating at high currents are sources of excessive heat generation, regardless of the application. Removal of this excessive heat is necessary not only for proper operation of the device, but also for longevity and reliability of performance. The solder attachment interface between a high power device and a particular substrate must be essentially void free. Voids are known to be very poor thermal conductors and jeopardize the efficient heat transfer to the heat sink or substrate. Reduction or elimination of voids is paramount to a successful heat transfer of power die attach. In our evaluation, we used a dedicated vacuum/pressure reflow furnace which has the capability to reduce voids with use of a pressure differential controlled process. Our results revealed successful achievement of low void concentration of <5%.

Equipment/Process/Materials/Test Samples

Utilizing an SST 5100 model vacuum reflow system, the initial effort was to compare a solid preform die attach versus solder paste die attach. The preform was a flat sheet of solder material just slightly smaller in area than the die. This preform was ~1-2 mils in thickness. The majority of die attach applications with a solid preform was done with AuSn material. The preform was placed between the die and substrate for subsequent melt of the preform to wet to both the backside of the Au-coated die and the Au surface of the substrate. The preform material was an 80Au20Sn with a eutectic temperature point of 278°C. No flux was used since this is a flux-less solder attach process with no need of oxide removal from the surface of the solid preform.

In our evaluation, we utilized a lead free SnAg solder paste consisting of 95Sn5Ag. The solder paste, Nordson EFD (95WS421) contains a water soluble flux designed for dispense and screen printing. The paste allows superior wetability to difficult surfaces such as nichrome and stainless steel. We evaluated this paste wetability on pure nickel and pure copper test coupons. In addition, we evaluated silicon die with backside gold metallization. The thickness of the nickel samples was 0.019 inch and the copper samples was 0.025 inch. It is essential that the metals were thin enough to allow our in-house Inspex X 90 X-ray system to penetrate and reveal the void concentration. Refer to "Fig." 1.

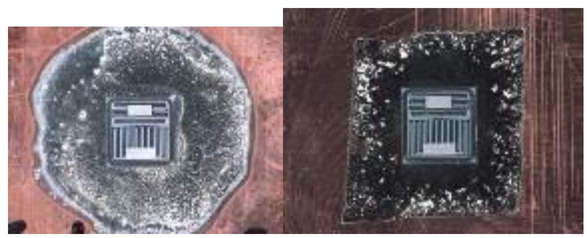
Figure 1: Model 5100 Vacuum Pressure Reflow Furnace and X-Ray System

Solid Preform versus Paste Void Comparison

SST has extensive experience with flux-less solid preform die attach not only with AuSn but also other solder preform alloys. A flux-less solder process is expected to produce lower voiding than any flux incorporated paste. However, customers have asked us to evaluate solder paste solutions to determine if they can achieve low void levels.

We developed an initial direct comparison evaluation to test this premise. A typical SST reflow solder profile for solid preforms was used. The solid preform material used was 95Sn5Ag 2 mils thick. The solder paste was screen-printed manually with a Kapton template of 4 mils thick. Silicon die (0.209 inch x 0.205 inch) with backside gold metallization were used on 0.015 inch thick copper substrates of 1 inch square size. Oversized preforms and oversized template openings were used to ensure enough solder material was available beyond the silicon die edge so as to not compromise this direct void comparison. Typically, this would not be performed for customer applications where the solder area is controlled not to excessively flow out beyond the device die edges. Refer to fig.2.

After Screen Printed Paste **After Reflow with flux residue**



After flux residue cleaning **After Solid Preform Reflow**

Figure 2: Example of Initial Reflowed 95Sn5Ag Samples of Solder Paste and Solid Preform

To ensure statistically significant data, the number of sample is relevant. With a larger number of samples the confidence level increases so the effect of outliers can be reduced. Therefore, a sample size of 16 parts per bin or group was determined to be suitable for this evaluation.

Methodology of Void Percentage Determination

X-ray evaluation is the industry standard method of obtaining the void concentration visually, assuming the parts are thin enough to allow penetration of the X-rays to reveal any voids.

To calculate void levels on the X-Ray system we performed the following procedure:

After acquiring the initial X-ray image of each sample, we:

(1) Used auto contrast to produce a contrast photo of the original X-ray image;

(2) Opened and loaded an all-white background;

(3) Subtracted the white background from the auto contrast image to further brighten the white void spots;

(4) Created a contour image to flatten the field image in order to equalize the image picture gray scale;

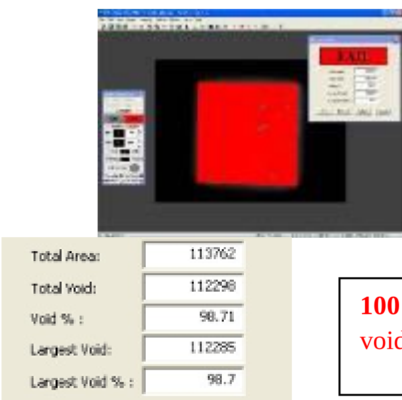
(5) Manually adjusted the contrast of this image for best contrast typically ~100;

(6) Engaged the void measure software

(7) Intentionally highlighted the darkened non-void areas (red color) and left the actual void areas (non-red). Refer to fig.3.

(8) Use the void calculator software to record the non-void area

(9) Subtracted the calculated non-void percentage from100% to get the actual void area percent.



100% -98.7% = 1.3% void area

Figure 3: Example of Inverse Void Calculation Progression

The boxplot (fig.4.) for solid preform vs. solder paste with the same generic die attach reflow verified that the flux-less solid preform produced the lowest void area vs. the solder paste with the same reflow profile. This was expected.

To demonstrate improved throughput, we created a new solder paste profile of <15 minutes total cycle time which showed void levels comparable to the solid preform. The new solder paste profile is patent-pending.

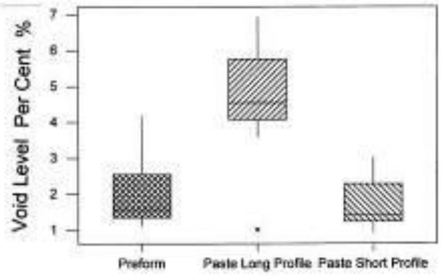


Figure 4 95Sn5Ag Preform versus 95Sn5Ag Solder Paste with Same Reflow Profile and Newly Created Short Paste Profile Silicon Die Soldered to Copper

As expected, the solid preform provided the lowest incidence of voids and highest reliability of the joints due to being a flux-free solder operation.

This has been supported by previously published papers.(footnotes 1,2,3,4) In reference 3, 2% is shown to be the minimum void concentration for flux-less die attach with solid preforms for large die sizes.

Customers desire a Paste Profile with Low Voids and Shorter Cycle Time

We developed a new profile to achieve a cycle time similar to a belt furnace, but producing lower void levels. Our target was to be below a 15 minute cycle time.

The new profile was used to evaluate the solder paste and was subsequently used to solder directly to nickel and copper. Test die coupons of a ~0.480 inch square of both nickel and copper were soldered to larger substrates of nickel and copper of 0.900 inch square. No gold metallization on either parts was used.

Test Procedure

Two stencil thicknesses of 5 and 10 mil thick, with an opening for the coupon die were used for this evaluation. The solder paste was manually applied across the stencil opening onto the bottom coupon substrate. The test coupon die was gently placed and centered onto the rectangular paste pattern. Four cavities in the graphite tooling held the assembled test coupons. The graphite tooling was placed into the vacuum pressure oven for solder reflow with an upper weight plate which placed a weight of 25 grams on each die coupon. After reflow with the new short paste profile, the samples were X-rayed for void measurement.

In order to best show the low void concentration achieved with the solder paste and new profile, we show here the X-ray images with a transparent overlay of a 10 x 10 grid where the X- ray image is sized to the grid. One can visually see the voids by determining the number of squares that are filled with the total void spots. Each single pocket cell is equivalent to 1%. By counting the number of filled cells of white void spots one has the void count of that test coupon. We show X-ray images of the four highest void test coupons and the four lowest void test coupons for two material combinations (Cu to Cu & Ni to Ni).
For metal to metal solder joints, electrical resistance tests were performed.

Electrical Resistance Test Procedure

Using top and bottom metal coupons we measured the contact resistance of the solder sandwich. This was done with a kelvin contact setup including a Keysight 34420A Micro Ohm Meter traceable to NIST and checked with a 1% 1 ohm resistor reading 1.00253 ohm. Refer to the following boxplot chart.

Results

Figs. 4A & 4B – Copper Test Die
Figs. 5A & 5B. – Nickel Test Die
Fig.6. – Test sample photo
Fig 7 – Solder contact resistance
Fig.8. - Metal Void Boxplot
Fig.9. - Silicon void boxplot

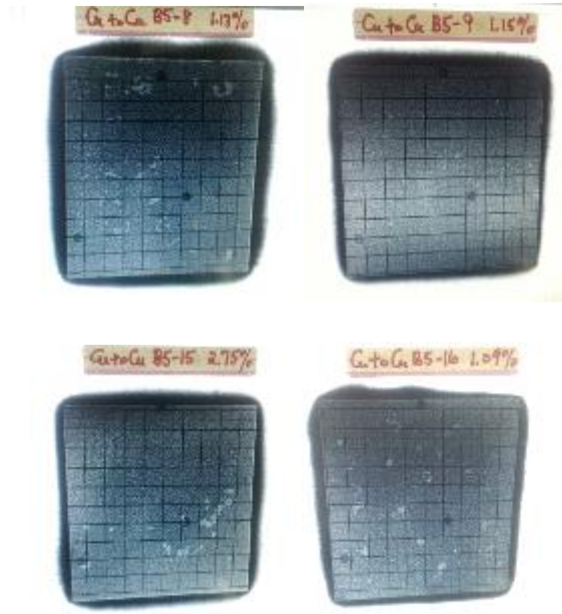


Figure 4A: Group Copper Test Die to Copper Substrate with 5 Mil Paste with the Four Highest Voids

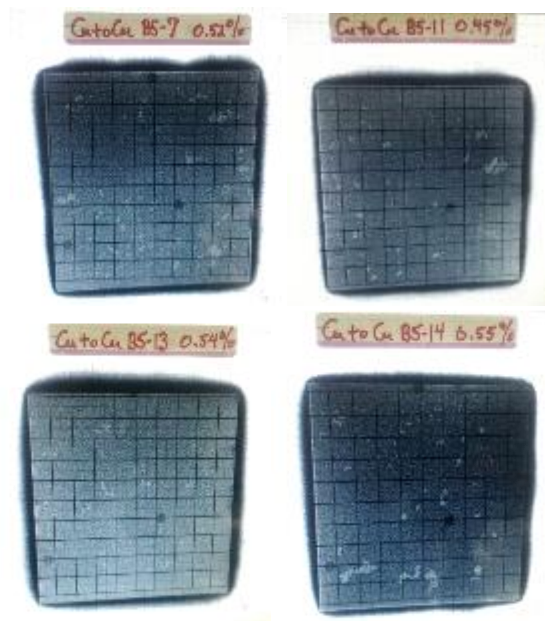


Figure 4B: Group Copper Test Die to Copper Substrate with 5 Mil Paste the Four Lowest Voids

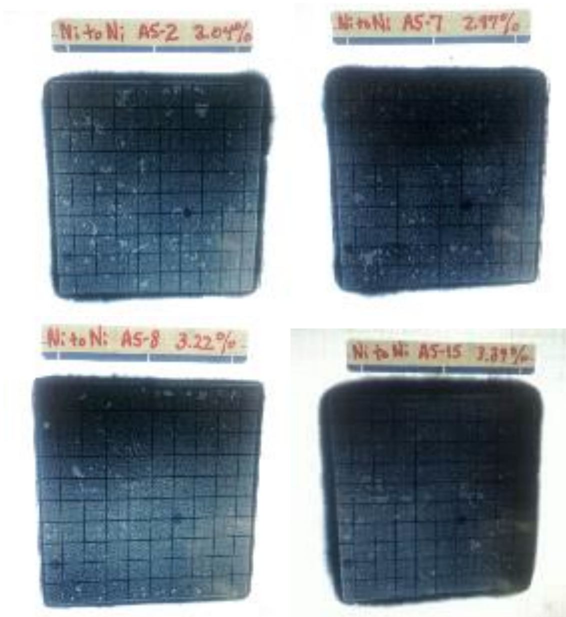


Figure 5A: Group Nickel Test Die to Nickel Substrate with 5 Mil Paste with the Four Highest Voids

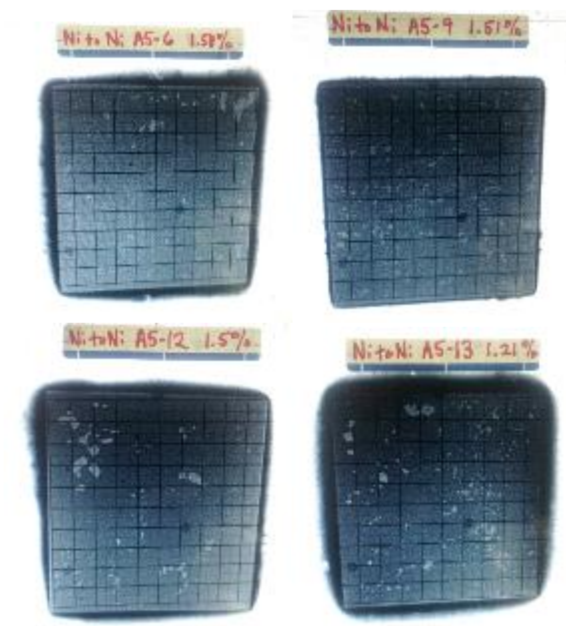


Figure 5B: Group Nickel Test Die to Nickel Substrate with 5 Mil Paste with the Four Lowest Voids

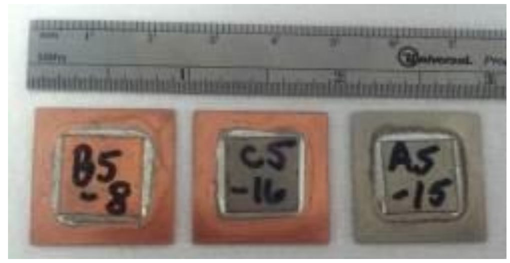


Figure 6: Samples of Void X-Ray & Electrical Test Samples

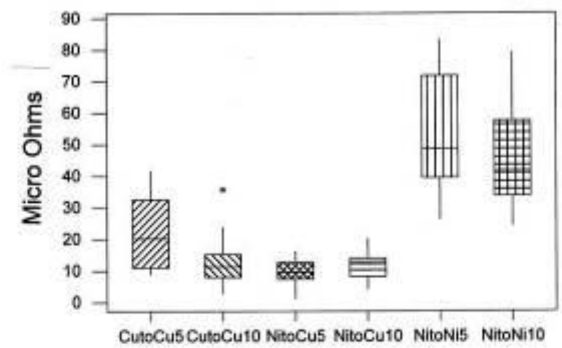


Figure 7: Electrical Testing for Solder Contact Resistance in Micro Ohms

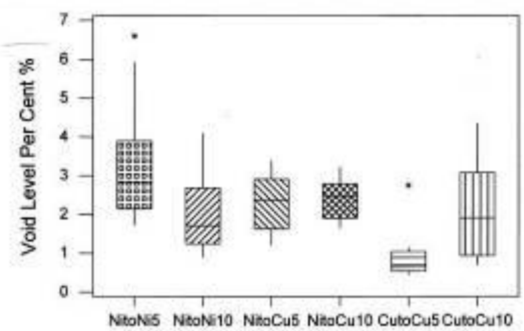


Figure 8: Boxplot of Void Level for all Metal Test Coupons

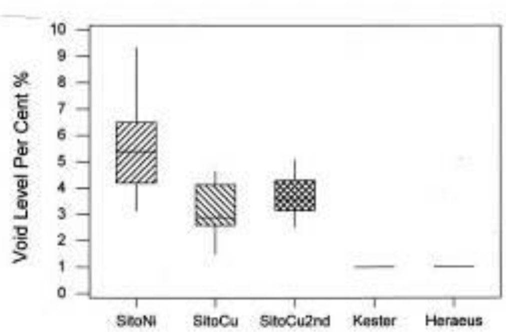


Figure 9: Boxplot of Void Level with Silicon Die to Metal Nickel Substrates 95Sn5Ag and PbSn Kester & Heraeus Paste

Summary

We successfully demonstrated the ability to achieve very low void concentration with a solder paste on nickel and copper. Metal coupon sandwiches of Ni to Ni, Cu to Cu, and Ni to Cu were reported. Average void concentrations below 5% were measured with a sample size of 16. It has been stated that typical solder paste void concentrations are from 10-20%. With our new profile, we achieved <5% at 13 min cycle time. Thus we propose an alternative to a belt furnace oven for solder reflow with the advantage of vacuum and pressure to significantly reduce the void concentration and increase production yields.

We continue to evaluate additional solder pastes and will report those results as they become available.

Acknowledgment

This evaluation could not have been done without graphite and test coupon fabrication by Trung Nguyen. we wish to acknowledge his talents and contributions.

References

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Key words: solder paste, 95Sn5Ag, vacuum and pressure reflow, flux, void free, solder reflow