A Case Study on Assembly Process Optimization of 0201 BTC Diodes for High Temperature

Prathik Rudresh
Vicor Corporation
MA, USA
prudresh@vicr.com

Chrys Shea
Shea Engineering Services
RI, USA

ABSTRACT

Assembling 0201 footprint components on a PCB is a challenge given their small size. The study addresses the difficulties faced during assembly of bottom terminated 0201 components, precisely diodes. A structured Design of Experiments was utilized to understand the effects of pad design, stencil apertures and solder paste on the diode assembly. The findings from this study has helped in optimizing the diode placement and reduced false calls on the AOI, thus reducing the cycle time of AOI workstation. The learnings from this study will be used for various future paste formulations and smaller footprint components, which is where the industry is headed.

Key words: 0201 Diode assembly, Tin Antimony, Lead free, high temperature reflow, aperture design

INTRODUCTION

Electronics miniaturization has been a key success strategy for original device manufacturers. This has led to drastic reduction in component size while the board densities have increased. Such trends have driven the development of ultra-small components with 0201 (Imperial) form factor (0.6 x 0.3 mm) that includes Bottom Terminated Components (BTC) such as diodes.

Despite the advantages of size and performance, 0201 components come with manufacturing and assembly complexities. Passive components, such as resistors and capacitors, typically have 3 or 5-sided terminations that allow solder to flow smoothly and create acceptable fillets during reflow. In contrast, BTC components have a single-sided termination, requiring precise solder volume control to ensure quality joints.

Common defects associated with these components include misalignment, solder bridging, insufficient solder deposition, tombstoning and open solder joints to list a few. These defects can significantly affect the reliability and performance of electronic assemblies. To mitigate these risks, manufacturers must employ advanced assembly techniques, precise component placement, and rigorous quality control measures to ensure product excellence and customer satisfaction.

BACKGROUND

High temperature Pb Free Reflow

Tin lead (Sn-Pb) solder has been the mainstay of conventional soldering process due to its low melting temperature, better wetting behavior, unique mechanical properties and lower cost. Historical evidence of using lead in solder showed harmful effects on environment and human health, thus leading to strict environmental laws discouraging use of lead in solder. [1] [2]

This led to development of Lead free solder alloys using tin with copper, silver, antimony, nickel or Zinc to list a few, as different elements of the alloys. Depending on the alloy composition, Pb free solders can be classified into high temperature or low temperature solder. High temperature solder applications have alloys such as Sn-Sb, Sn100C, Sn-Cu, etc. These high temperature solders are used (but not limited to) in power conversion applications, server and mainframe applications, automotive under-the-hood power management applications, military/aerospace applications requiring a lead-free material that can withstand the higher operating temperatures, offer vibration resistance, and deliver high-temperature (>125°C) thermal cycling reliability levels beyond those available with current commercialized SAC materials. [3]

As 0201 components continue to play a pivotal role in advanced electronics, optimizing the assembly process becomes crucial to improving yield and performance. This study explored the application of Sn-Sb alloy, which has liquidus temperature of 240ºC and solidus temperature of 237ºC.

EXPERIMENTAL

Experimental Design

The experiment was executed on production equipment that included:

- DEK NeoHorizon Printer
- Clean, new squeegee blades

- One laser cut and nano coated stencil
- Type 4 and 4.5 tin antimony solder paste with flux formulations below
  - Flux A Indium 3.2 HF
  - Flux B Indium 6.6 HF
- Parmi SigmaX – SPI
- ERSA Hot Flow 10 reflow oven
- Parmi Xceed DSI – AOI

Procedure

A new PCB design in development was selected as the test vehicle; the vendor recommendation for pad layout was incorporated.

The necessary solder paste was ordered in advance, ensuring they were available and prepared for use during the DOE runs.

Prior to running the experiment, the paste was kneaded to bring it to its working viscosity range.

The run order included both forward and reverse strokes of the squeegee to eliminate any effects of systemic variations. The experiment was blocked to use one paste at a time due to inefficiencies in changing back and forth between pastes.

Two different aperture geometries were designed on a nano coated stencil. The stencil was thoroughly cleaned in an automated stencil cleaner between runs.

New squeegee blades were installed for the experiments and cleaned thoroughly during solder paste change over.

The reflow profile was developed using Solderstar datalogger and was subsequently validated by the solder paste supplier prior to the experiment.

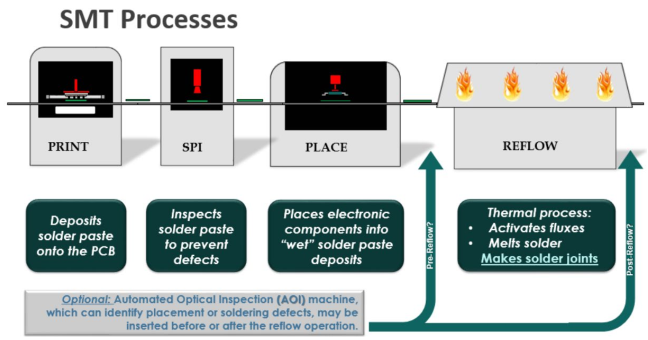


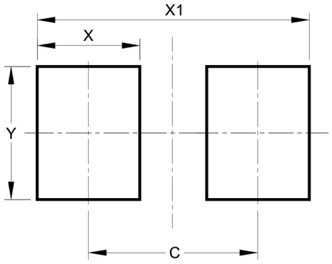
Figure 1. The SMT process flow for the experiment

The collected Solder Paste Inspection (SPI) data was exported and analyzed using JMP and Minitab statistical analysis software. The Automated Optical Inspection (AOI) validated the placement of the components post reflow as per IPC 610-A standards.

ANALYSIS

Pad Dimensions

The pad dimensions on the substrate were reviewed on a previous product to understand their effects on the solder joint formation. The vendor recommended pad dimensions on 0201 diodes was 0.3 x 0.23 mm with 0.15 mm of distance between pad centers as shown in Figure 1.



Dimensions	Value (in mm)
C	0.380
X	0.230
X1	0.610
Y	0.300

Figure 2. Vendor recommended 0201 Diode Pad dimensions

The IPC 7525-C guidelines for Stencil aperture recommends that the pad dimension for a 0201 Imperial device be 0.25 x 0.40 mm. The vendor recommended pad designs were within the IPC guidelines, therefore the vendor suggested pad stack was used for this study.

Stencil Apertures

IPC 7525-C recommends stencil aperture opening of 0.23 x 0.35 mm with stencil thickness range of 2.95 – 4.92 mils and Area Ratio 0.56-0.93 for 0201 chip components. At the time of publication, there are no recommendations for BTC 0201 components.

In the absence of established aperture designs, the following two designs as shown in Table 1 were used.

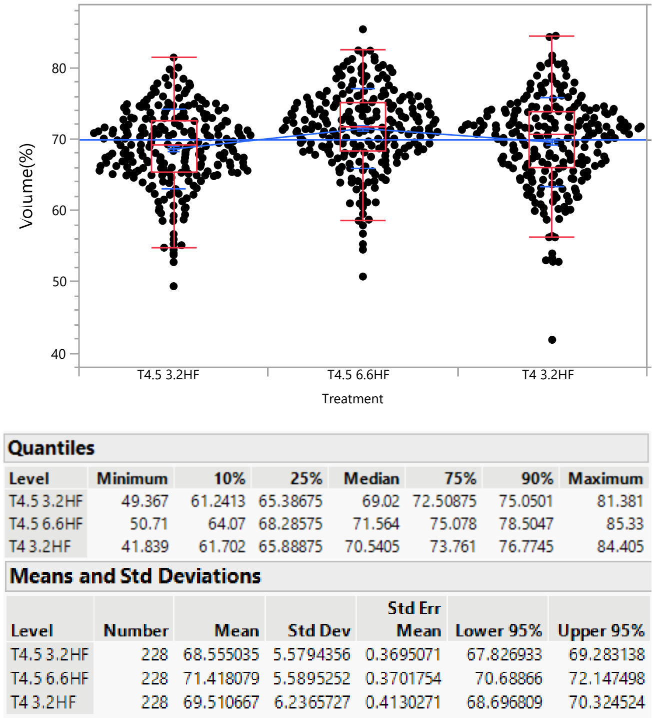
Table 1. Stencil Aperture Details (dimensions in mm)

Aperture Design	Dimensions (um)	Dimensions (mils)	Area Ratio
AD1	0.23 x 0.30	9 x 11.8	0.68
AD2	0.21 x 0.23	8.3 x 9	0.58

Printing – SPI

Aperture Design 1 printed better than Aperture Design 2, primarily because it has a higher area ratio which enables better Transfer Efficiency (TE).

Printed samples were measured using SPI and plotted using Volume percentage Vs Treatment. This graph shows the spread of the different paste types when printed with same print process parameters.



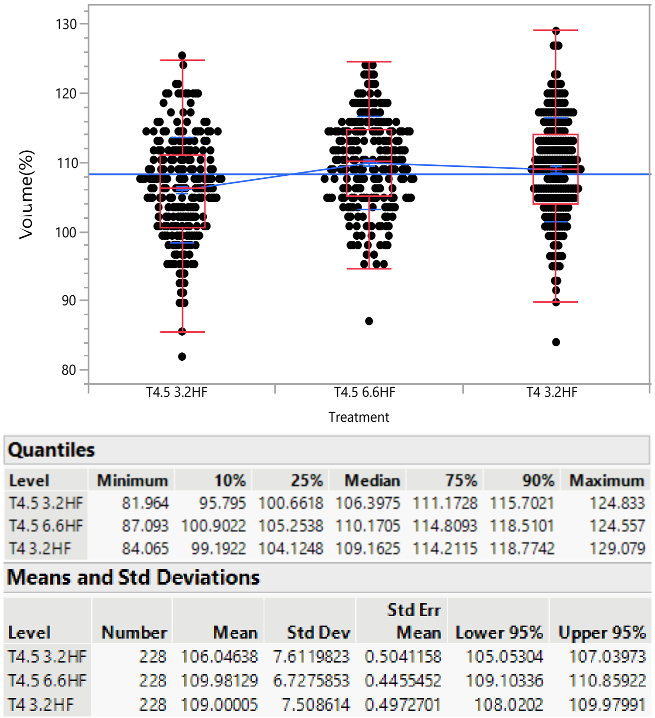
Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
T4.5 3.2HF	49.367	61.2413	65.38675	69.02	72.50875	75.0501	81.381
T4.5 6.6HF	50.71	64.07	68.28575	71.564	75.078	78.5047	85.33
T4 3.2HF	41.839	61.702	65.88875	70.5405	73.761	76.7745	84.405

Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
T4.5 3.2HF	228	68.555035	5.5794356	0.3695071	67.826933	69.283138
T4.5 6.6HF	228	71.418079	5.5895252	0.3701754	70.68866	72.147498
T4 3.2HF	228	69.510667	6.2365727	0.4130271	68.696809	70.324524

Figure 2. SPI data analysis of Aperture Design 2 (AD2) apertures using JMP software



Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
T4.5 3.2HF	81.964	95.795	100.6618	106.3975	111.1728	115.7021	124.833
T4.5 6.6HF	87.093	100.9022	105.2538	110.1705	114.8093	118.5101	124.557
T4 3.2HF	84.065	99.1922	104.1248	109.1625	114.2115	118.7742	129.079

Means and Std Deviations

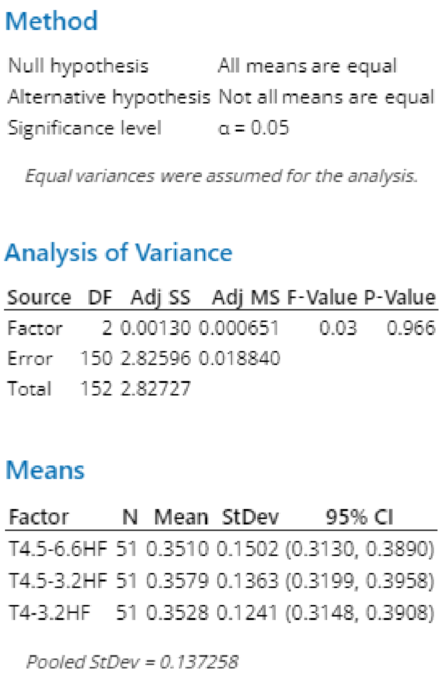
Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
T4.5 3.2HF	228	106.04638	7.6119823	0.5041158	105.05304	107.03973
T4.5 6.6HF	228	109.98129	6.7275853	0.4455452	109.10336	110.85922
T4 3.2HF	228	109.00005	7.508614	0.4972701	108.0202	109.97991

Figure 3. SPI data analysis of Aperture Design 1 (AD1) apertures using JMP software

Shear Testing

There was no statistically significant difference in shear strength between the two aperture designs.

Samples built were shear tested for evaluating joint strength of BTC 0201 Diodes.



Method

Null hypothesis	All means are equal
Alternative hypothesis	Not all means are equal
Significance level	α = 0.05

Equal variances were assumed for the analysis.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	2	0.00130	0.000651	0.03	0.966
Error	150	2.82596	0.018840		
Total	152	2.82727			

Means

Factor	N	Mean	StDev	95% CI
T4.5-6.6HF	51	0.3510	0.1502	(0.3130, 0.3890)
T4.5-3.2HF	51	0.3579	0.1363	(0.3199, 0.3958)
T4-3.2HF	51	0.3528	0.1241	(0.3148, 0.3908)

Pooled StDev = 0.137258

Figure 4. ANOVA Analysis of shear strengths using Minitab 18

The ANOVA analysis yielded a p-value of 0.966, suggesting that the observed differences in the group means are likely due to chance. Therefore, the null hypothesis of equal means could not be rejected, indicating no significant difference among the group means.

AOI False Calls

AD2 produced fewer false calls for skewed components than AD1.

Automated Optical Inspection is used post reflow to validate the placement of components as per IPC 610-A acceptability standards. The AOI system flags components suspected of not meeting the acceptability criteria, requiring operator intervention and determination of the call. If the operator determines that the component meets the IPC acceptability criteria, it is counted as a false call. Drastic reduction in AOI false calls was observed for diodes using AD2 stencil apertures. Figures 5 and 6 show the typical skewed observed with AD2 and AD1, respectively.

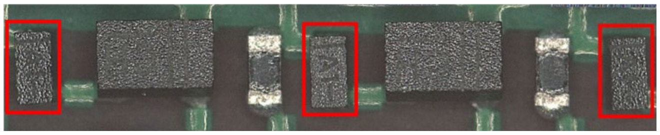


Figure 5. 0201 Diodes that used AD2

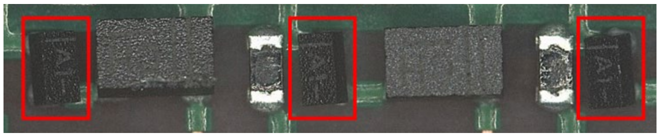


Figure 6. 0201 Diodes that used AD1

INFERENCES FROM FINDINGS

The print quality on these tests was similar between the flux and particle size matrix used in the experiment. This leads to conclusions that:

- The particle size, in other words Paste Type did not have significant impact on printing. The T4 and T4.5 paste with flux A had similar printing results.
- Flux A and flux B did not have an effect on improving the printing properties. However, flux B deposited marginally higher volume indicating higher tack and better release properties.

Two types of stencil apertures were considered, AD1 and AD2. The printing performance for both apertures were different in terms of volume. This leads to conclusion that:

- Area Ratio (AR) of 0.58 had less TE compared to 0.68. Higher the AR, better release during printing. Based on the tests, about 35% reduction in printed volume was observed.
- **Reduction in volume is beneficial** as excessive volume could lead to the device skewing/floating during reflow.

X-ray evaluation of the solder joint showed that AD1 had solder shorts under the component, while AD2 aperture design demonstrated superior joint integrity. The study does not evaluate components built with AD1 further due to electrical failures.

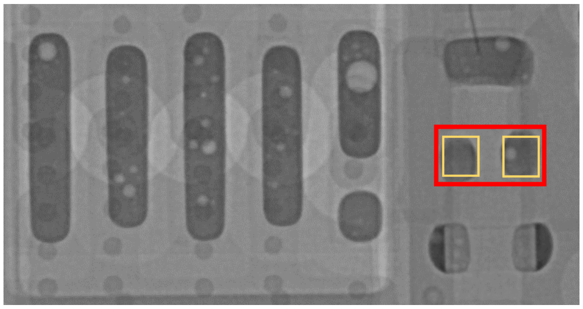


Figure 7. X-ray of AD2 Stencil Aperture

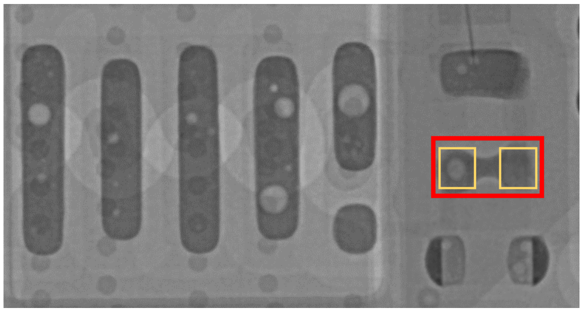


Figure 8. X-ray of AD1 Stencil Aperture showing solder short under component

It was observed that the skew drastically reduced for components assembled with AD2 stencil apertures. This could lead to conclusions:

- When using AD1 apertures, excessive solder on the pad and beneath the diode might be inducing a buoyant force, causing the diode to float during the reflow process and potentially leading to skew.
- AD1 apertures with excessive solder can increase the surface tension of the molten solder, potentially causing the diode to float and preventing proper joint formation. This could result in a defect mode similar to "Head in Pillow" (HIP) or non-wets, where the component appears to be soldered in place but the solder has not adequately wetted to the component pad.

CONCLUSIONS

While AD1 printed better than AD2, AD2 reduced shorts, skewing and false calls, indicating that there is more to quality and productivity than just good prints; the effect on the entire line should be measured and considered.

This case study considers the effects of PCB pad design, stencil aperture design, the flux formulation in the assembly of 0201 BTC diodes using high temperature lead free solder. The study recommends the consideration of supplier recommended pad designs for 0201 BTCs. Generic aperture designs for 0201 chip components provide too much solder for the BTC-style termination.

Adopting the strategy of looking at the product and production holistically, manufacturers can overcome the challenges associated with assembling 0201 diodes and ensure the production of high-quality electronic products.

By presenting these insights, this paper aims to contribute to the broader understanding on assembly process optimization for ultra-miniature components that are increasingly vital in design and manufacturing of next generation electronics.

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