GOLDEN LINE-DRIVEN DESIGN AND PROCESS SOLUTIONS FOR MOLD FLASH ELIMINATION IN HIGH-DENSITY WLF QFN MANUFACTURING

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ABSTRACT

Wide lead frame (WLF) technology has supersized the assembly of Quad Flat No-Lead (QFN) devices by increasing the units per strip by 80-100%. However, this high-density assembly gain was offset by a 2-5% yield loss attributed mainly to mold flash defects. To drive yield recovery and operational efficiency, a comprehensive investigation was conducted employing root cause analysis techniques including signature profiling, fault tree analysis, and design of experiments (DOE). Process and tool touchpoint mapping enabled identification of the primary flashing causes: (1) fulcrum effect from high tower insert design, (2) unbalanced chase-to-pin planarity due to pin-type chase, and (3) insufficient mold release film coverage.

Lean principles of waste reduction and continuous process improvement guided the implementation of targeted design innovations and a Golden Line strategy. Vertical flashing was eliminated by standardizing low/no tower inserts and shimming high tower inserts for planar wire bonding surfaces. Vent side flashing was mitigated with a slit-type mold chase design that addressed vacuum pin denting risks. Additionally, a mold release film with thicker adhesive improved sealing to reduce compound seepage.

Through this lean-inspired, data-driven Golden Line approach, mold flash defects were reduced by over half, resulting in a <5% yield improvement in WLF QFN assembly. The integrated methodology not only enhanced product quality but also unlocked significant cost avoidance, reinforcing the value of process optimization and waste minimization in high-density semiconductor manufacturing.

1. 0 INTRODUCTION

The lead frame is an integral part of the Quad Flat No-Lead (QFN) package; thereby its assembly has been supersized through the introduction of the wide lead frame. Generally, the QFN assembly process involves (1) mounting of die/s on the lead frame, (2) wire bonding of die/s to the leads, (3) molding, and (4) saw singulation. These assembly processes were initially carried out on *standard* lead frame (SLF) which allowed for production of hundreds to thousands of units in a strip. To fully maximize capacity with every index and every mold shot, the lead frame size was increased by 30-60% in area to create the wide lead frame (WLF)—which is the current desired state.

The continuous ramping of wide lead frame in the site did not come without any challenges. Naturally, the change required tool upgrades, modified peripherals, and new recipes which called for the investment of time and resources—all of which were necessary to facilitate up to 80-100% increase in the units per strip (UPS). However, with the WLF conversion, the yield dropped significantly, counteracting the supposed gains from the increased capacity. The larger lead frame area along with the removal of panel reinforcements made the strips more prone to warpage. This characteristic of the WLF significantly impacted the film-assisted molding process, especially since the strip is now more susceptible to contours where mold compound can seep through.

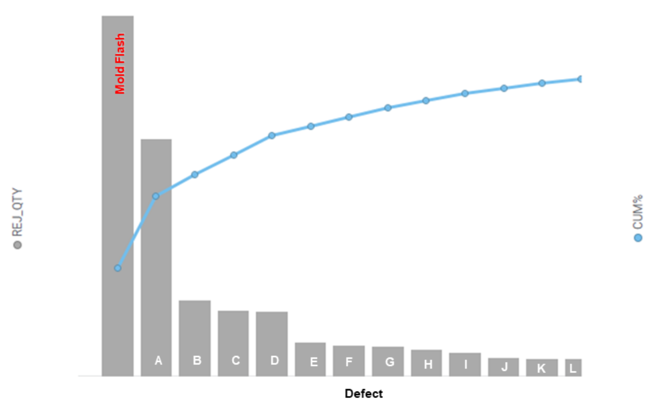


Figure 1. *Wide Lead Frame Top Defect Pareto for 2024. Mold flash is seen to be one of the top defects impacting the WLF Yield.*

In fact, mold flashing is the top defect contributing <5% loss to the WLF yield. Flashing occurs when mold compound flows through the gaps between the film and the lead frame during molding. These gaps may be caused by lead frame dents induced in the previous processes pre-molding (i.e. die attach and wire bond) or by misalignments or nonplanarity during the molding process.

The high rejection rate of mold flashing on WLF consequently adds several days to the cycle time per lot due to the increase outlier lots put on hold. Furthermore, approximately millions of dollars' worth of units are being scrapped yearly due to mold flashing on WLF devices. With the rising penetration of WLF in the pipeline, it is imperative to engineer solutions to reduce mold flashing during the assembly process.

However, since the root ca uses for flashing cannot simply be isolated in the Mold process, there is an impetus to build a golden line that would introduce little to no dents and warpages on the lead frame prior and during molding. This golden assembly line would consist of the ideal process conditions and ideal tool peripheral designs to churn out mold flash-free devices. For the sake of this study, focus will be given on the top mold flashing signatures which constitutes majority of the cases observed for WLF. In particular, the key actions and innovations developed at Wire Bond and Mold will be discussed in detail.

2. 0 REVIEW OF RELATED WORK

Not applicable

3.0 METHODOLOGY

The strategy to effectively develop a golden assembly line consists mainly of four steps: (1) Signature Profiling; (2) Fault Tree Analysis; (3) Process and Tool Touch Point Mapping; and (4) Design of Experiments.

3.1 Mold Flash Signature Profiling

Signature profiling is a critical first step to fully understand any mold flashing problem. Every unique root cause produces a unique mold flashing signature; hence, it is important to characterize the location of the flashing on the unit-level and strip-level, the severity or thickness of the flash (light or heavy), the frequency of the strip-level patterns or localization (i.e., all strips, alternating, isolated, etc.), as well as if there are any other notable marks on the affected strip/s.

The existing mold process workflow requires the production specialists (PS) to perform surveillance on every lot to check for mold flashing and other defects on the newly molded strips. Any defect noted on each strip are rejected on the electronic map (e-map). In case heavy flashing or localized flashing is observed after surveillance, the PS is required to immediately shut the tool down for repair to stop propagation of mold flashing on the succeeding strips and lots.

E-Mapping allows for documentation of the mold flashing rejects and their location on each strip of a particular lot which already gives clues on where on the strip were dents or nonplanarity occurred. However, it is also critical to illustrate where the flashing occurs on the unit-level: whether flashing is seen on the leads or on the pad, if it is only on specific pins, if it is only on the long side or the short side of the unit, etc. This information would help distinguish whether the flashing is inherently induced from the wire layout or even from the lead frame design.

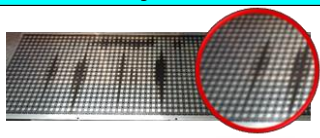
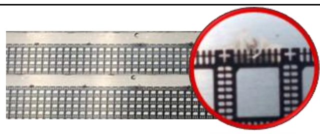
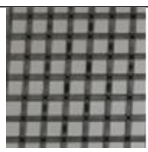
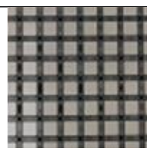
Another crucial check item in signature profiling is the lightness or heaviness of the flashing. This indicates the severity of the contour or nonplanarity on the lead frame during molding.

On a strip level, any mold flashing patterns and localization tells a story on where dents and warpage were induced and which process and equipment may have caused them. The frequency of the same patterns and localization on the lot level paints a bigger picture on the analyses of mold flashing. If the same signature is seen across all strips of the lot, it is more likely to be induced pre-molding—perhaps on the wire bonder or die attach tool—since the mold tool usually consists of multiple presses with two cavities each; hence, due to press-to-press and even cavity-to-cavity variation, a unique flashing signature is less likely to be produced by all presses and cavities in the mold tool. If the flashing signature is seen only on specific strips, it should be checked if the affected strips were processed on the same cavity or the same press which could signal an anomaly within a specific mold press. If there is no mold cavity commonality but the same signature is seen on consecutive strips, it is possible to have been induced prior molding but was resolved after intervention. Nevertheless, all this information would provide a good starting point for the mold flash investigation. A deep dive on the tool commonality, lead frame commonality, and even device commonality would be the next key steps to aid in the investigation.

As reference, a Mold Flash Library was created to document all known flashing signatures and their verified root causes for ease in disposition of the affected lot and repair of the affected tools. This reference is continuously being updated with new root causes and lessons being discovered.

For the interest of this study, focus was given on the top three (3) mold flash signatures based on their contribution to the total yield loss. These signatures were tabulated in **Table 1**.

Table 1. *Top Mold Flash Signatures based on their impact contribution to the total WLF yield loss.*

	Signature	Description	Impact
A		Vertical heavy and gross flashing on the leads and pad. Vertical signature shown in repeating pattern across the strip. All or most strips affected in a lot.	<3%
B		Light to heavy flashing on the vent side of the strip. Circular pin-hole marks usually seen near the flashes	<1%
C	 	Unit-level light to heavy flashing on the center of the leads. Most or all units are affected (every panel). Most or all strips are affected.	<1%

3.2 Fault Tree Analysis

Once the flashing signature has been fully characterized, a fault tree analysis was used to examine the potential failure points that may have caused mold flashing. Initially, the macro-process map of the assembly process was revisited to identify which process step may have contributed to the defect. Expectedly, every step prior mold—and essentially every step involving processing the units on the lead frame—were identified as the critical processes that would impact mold flashing. Hence, these major log points were further broken down to be analyzed (see **Figure 2**).

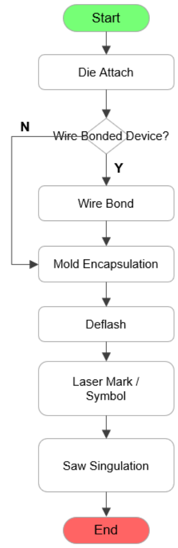


Figure 2. *Macro Process Map of Generic Assembly Process.*

The Supplier-Input-Process-Output-Customer (SIPOC) diagrams of die attach, wire bond, and mold processes were reviewed to pinpoint all the relevant elements of each process that could introduce dents and nonplanarity on the lead frame that would then result to mold flashing.

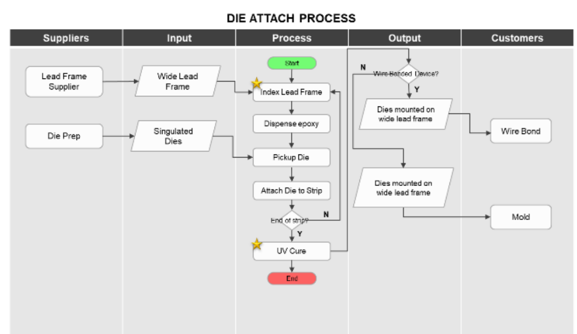


Figure 3. *Supplier-Input-Process-Output-Customer (SIPOC) diagram of Die Attach Process.*

In **Figure 3**, the die attach process steps found to be most relevant to mold flashing and would induce the most warpage on the leads are the indexing process and UV cure. Indexing involves mechanical clamping that may introduce some areas of nonplanarity on the strip due to the applied force. Additionally, unoptimized temperature profile may also cause the lead frame to warp during the cure process.

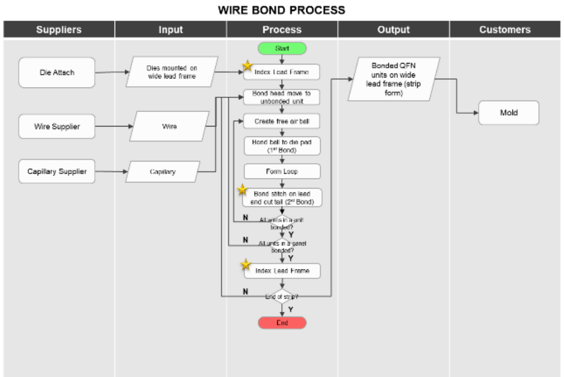


Figure 4. *Supplier-Input-Process-Output-Customer (SIPOC) diagram of Wire Bond Process.*

For wire bond, the key steps identified to have the most impact on mold flashing are the indexing and 2nd bond processes (See **Figure 4**). These processes directly apply some pressure or force on the lead frame thereby causing buckling on the strip. In particular, the combination of heat, force, and ultrasonic energy during 2nd bond and tail cutting may put on too much stress on the leads and/or result in leads bouncing. When the latter occurs, it is possible that the tension from the bonded wire may hold the nonplanar position of the leads in place, giving an opening for mold compound to seep through.

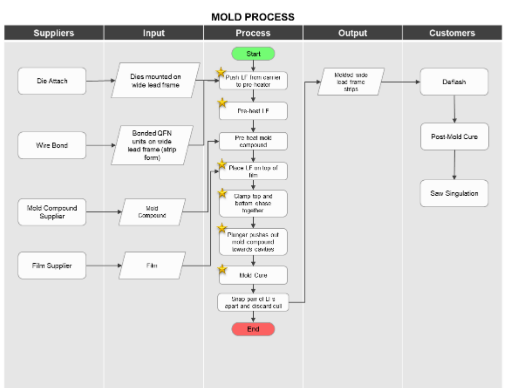


Figure 5. *Supplier-Input-Process-Output-Customer (SIPOC) diagram of Mold Process.*

Although most of the processes in mold inherently contributes to flashing, those that would most likely cause mechanical stress on the lead frame and those that are relevant to the top mold flash signatures were highlighted in **Figure 5**. Logically, the mold transfer profile dictates the mold flow, hence, the parameter settings in step 6 would impact flashing. Similarly, if the clamping pressure is excessive or insufficient, mold flashing can also arise. Temperature plays a significant role in determining the mold transfer profile, thereby the pre-heat and cure steps are also critical factors to consider. On the mechanical side, if too much force is applied when pushing the lead frame from the carrier to the pre-heater, or if an error occurred during this step, dents may be introduced on the strip and cause flashing. Moreover, when the lead frame is not placed flatly on the mold release film, or if misalignment occurs during molding, flashes would appear on the back side of the strip.

From the critical steps and factors noted from the three log points, a fault tree analysis (FTA) was built. The FTA was used as guide in the validation process to determine the most probable root causes of the top mold flashing signatures encountered, which were further categorized to be man-, machine-, method-, and material-related. (See **Appendix 1**)

3.3 Touch Point Mapping

The verification of the possible root causes identified in the FTA was kickstarted through touch point mapping. From the location and localization observed for each of the signatures in **Table 1**, several root causes—particularly those that involves manual handling—were already eliminated since the signatures noted were more systematic than random.

The vertical pattern noted on Signature A were found to be coinciding with the width of the "tower" on the wire bond heater block insert (the elevated part). This is a strong lead that was further explored in the next phase. Signature B flashing is generally on the periphery of the strip; hence, they were possibly induced on the clamping area during molding. It is also possible for the lead frame gripper used during indexing at wire bond to induce flashing on the periphery; however, since that on Signature B is localized on the vent side, this root cause (which only occurs on the gate side) was eliminated.

Signature C was noted on most, if not all, units on the strip and was found to coincide with pins where wires were bonded (based on the bonding layout) and were most likely induced during 2nd bonding/tail-cutting. Furthermore, none of the signatures seem to tie back to possible failure modes at die attach; thereby the identified strategies were geared towards wire bond and mold processes.

3.4 Design of Experiments (DOE)

While touch point mapping already ruled out several root causes, additional data from experiments can further break down the elements contributing to the failure mechanism. For each flashing signature, several splits were identified and have undergone sets of simulations in attempts to replicate them.

3.4.1 Vertical Flashing (Signature A)

The simulations for Signature A were designed to determine if the lead frame design, wire bond indexing, and the wire bonding process itself is causing the vertical signature. Although the initial hypothesis was that the flashing was caused by the insert and clamp during wire bond indexing, it is still vital to determine what makes it turn on and off.

For the simulations, a large package driver device was selected which was one of the packages exhibiting the vertical signature. The worst-performing wire bond tool and mold tool (same press and cavity) were used for all splits to eliminate any tool-to-tool variation. Two lead frame part numbers were chosen: one with the highest mold flash DPPM (*"Bad LF PN"*) and one with the lowest mold flash DPPM (*"Good LF PN"*). Two types of insert were also used: one with the elevated heater block design (*"With Tower"*) and one with the flat heater block design (*"No Tower"*).

The different splits also undergone varying wire bond conditions: (1) indexed or unindexed; (2) with die or without die; and (3) with wire or without wire. A total of 8 splits were done for this validation and the results are further discussed in Section 3.1.

3.4.2 Pin-Hole Flashing (Signature B)

Film assisted molding makes use of film for the protection of mold chase surface from the mold compound reducing the abrasion. Film also provides coverage to the lead frame avoiding seepage of mold compound to leads and pads. To hold and flatten the film during molding, a vacuum system is distributed along the periphery of chase surface. Pin serves as plug to the vacuum hole to controlling the vacuum pressure.

To validate the flashing signature on the vent side of the strip, mold chase balancing was initially performed on the affected tools. Mold chase pins were further inspected to check for their condition. For the simulations, a smaller package device more prone to vacuum pin flashing was selected.

3.4.3 Leads Flashing (Signature C)

From signature profiling and touch point mapping, leads flashing were found to be mostly induced by tail-cutting during wire bonding. However, there is an opportunity to minimize its effects through improvements on the mold release film.

Mold release film is composed of base layer and adhesive layer. Base film forms contact with the mold chase while the release layer adheres to leads and pads. Release layer acts as cushion to cover lead frame contours and blocks excess mold compound flowing into the pad and leads. Mold compound may seep into areas between film and lead frame due to factors such as non-planarity on the leads and lead frame, the chase, or the film itself.

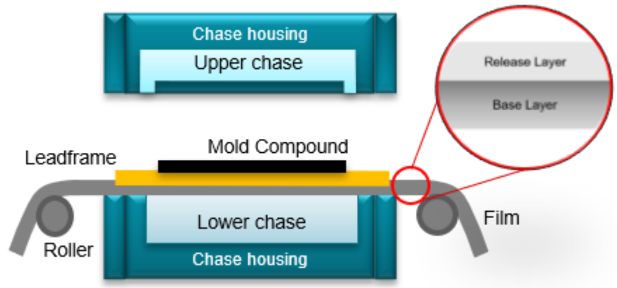


Figure 6. *Mold chase configuration and mold film layers*

Two types of film from two existing suppliers were used in this study:

(a) Mold release film with X base layer and Y release layer
(b) Mold release film with 1.5X base layer and 0.5Y base layer

Material properties comparison is summarized in **Table 2**.

Table 2. *Material properties of the mold release films from Supplier A and Supplier B.*

Material property comparison		**Supplier A**	**Supplier B**
Base film	Composition	Polyethylene terephthalate (PET)	Polyethylene terephthalate (PET)
	Thickness, µm	X	1.5X
Release layer	Composition	Acrylic resin	Acrylic resin
	Thickness, µm	Y	0.5Y
Total thickness, µm		X+Y	1.5X + 0.5Y

The test vehicle used was a large package lead frame with the worst mold flash DPPM. Total of 160 lots were used in this study. Units were subjected to automated visual inspection to quantify units with flashing and compare the performance of the two film types.

4.0 RESULTS AND DISCUSSION

Upon completion of the experiments and validations, the key factors resulting in the top three flashing signatures were pinpointed. From these factors, the best possible solutions to make the line conditions more robust and increase the process margins against flashing were engineered.

4.1 No Tower Insert and Clamp Design at Wire Bond

The results of the DOE on Signature A (See **Appendix 2**) revealed that the vertical flashing can be replicated through the combination of indexing and wire bonding of the Bad LF PN with dies on high tower insert. However, it is also worth noting that light flashing was also observed when the Bad LF PN was indexed through the wire bonder regardless of the heater block design; this reveals that there is some level of weakness on this particular lead frame design. Still, the use of the high tower insert aggravates the mold flashing and results in flashes that are irrecoverable even with chemical deflash.

The elevation or tower on the heater block insert instigates a fulcrum effect between the part of the lead frame that is staged during wire bonding and the parts that are "floating" on the lower parts of the insert. The edges of the tower touching the lead frame serves as the fulcrum point during indexing or clamping, resulting to buckling. This failure mechanism is illustrated in **Figure 7**.

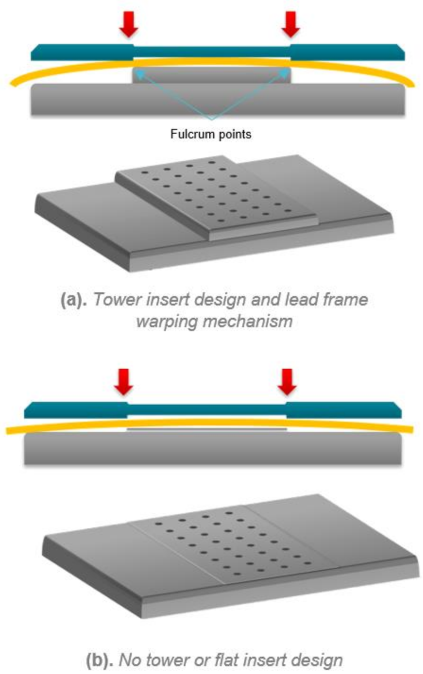


Figure 7. *Comparison between the clamping mechanism of (a) the high tower insert design, and (b) the flat or no tower insert design.*

Attempts to optimize the machine handling system (MHS) parameters to compensate for the effects of the high tower insert were unsuccessful. Due to the frequency of conversions at wire bond, it would be difficult to standardize the mechanical setup even after using the exact same MHS parameters. Furthermore, varying response may be expected since multiple insert tower heights are being used in production: the high tower design, the low tower design, and the no tower design. Additional simulations have shown that vertical flashing is observed only on the high tower inserts while only very light flashing is seen on the lower tower inserts.

With this information, the interim action was to execute machine conversions to eliminate the high tower inserts installed in production. Through the exclusive use of low tower height inserts in the line in parallel with rework of high tower inserts, 25-35% DPPM reduction was already realized.

4.2 Slit-Type Bottom Mold Chase Design

The existing pin-type vacuum mold chase design makes use of pins to support the bottom film to prevent deformation during molding. However, this design was found to be highly susceptible to nonplanarity and debris accumulation.

Results of the simulations showed that condition of the pin impacts the planarity of film causing mold flashing as summarized in **Figure 8.**

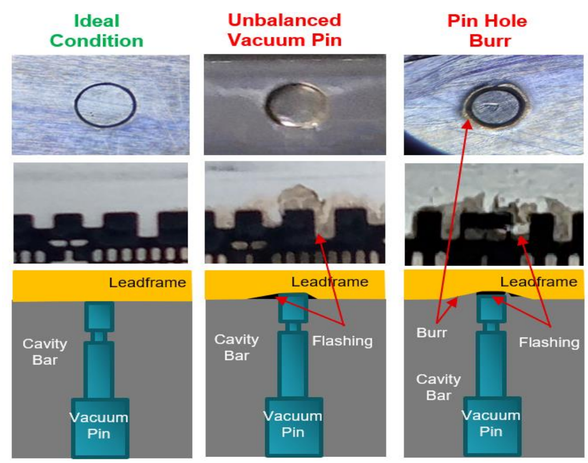


Figure 8. *Pin conditions impacting film planarity.*

Once the mold compound enters and clogs the vacuum pin holes, the pins may protrude and induce dents on the strip periphery, resulting to mold flashing and affecting live units as seen in Signature B.

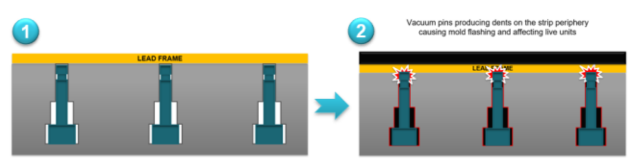


Figure 9. *Mold flash failure mechanism on the vacuum pin-type mold chase.*

Due this risk, regular pin replacement and maintenance is required to minimize the occurrence of this flashing signature. However, the maintenance and cleaning of vacuum pins is a time-consuming and tedious activity that would require several hours downtime per chase.

To address the mold flash issue without compromising productivity and cycle time, slit-type mold bottom chase was designed. Instead of vacuum pin holes, intake hole grooves were used to create slits on the cavity bar. Through this design, there are no moving parts that may produce dents on the lead frame during molding. The new design also facilitates easy disassembly for chase cleaning and maintenance with the removable cavity bar. This also eliminates the risk of damaged vacuum pins which are normally induced during chase cleaning and maintenance.

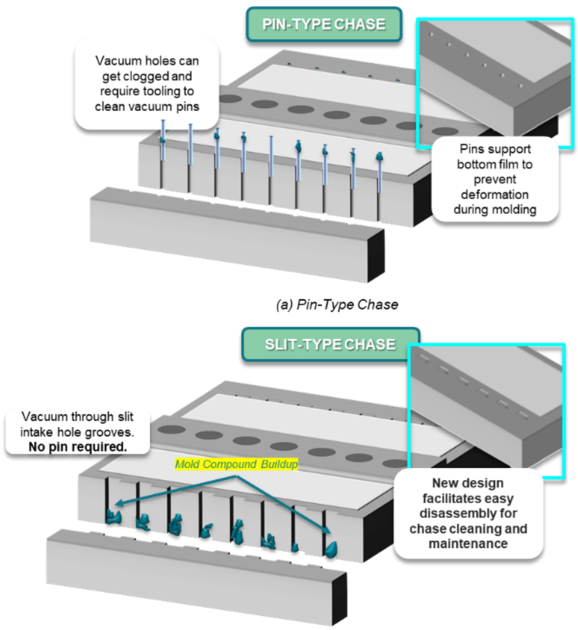


Figure 10. *Comparing pin-type vs. slit-type mold chase designs.*

4.3 Thicker Bottom Film Adhesive

Through signature profiling and touch point mapping, the gross flashing on the leads (Signature C) was found to be mainly induced during wire bonding. Leads warping was observed due to the impact of the 2nd bond or tail-cutting at wire bond, especially with devices using large wire diameters. While the application of the specialized parameter and optimization of the stitch placement could help alleviate the warpage produced from wire bonding, additional measures can be performed to further contain and reduce its mold flashing impact.

To increase process robustness at mold, the bottom release film can be further improved. The existing bottom film has a thin adhesive that makes it prone to slipping; however, this was resolved with the use of film holding system via bearing with one-way roller for consistent bottom film tension. Still, the thin adhesive of the base film could only offer minimal cushion for contours on the lead frame. Hence, the use of thicker adhesive release film during molding would better seal in gaps between lead frame and film to reduce risk of compound seepage.

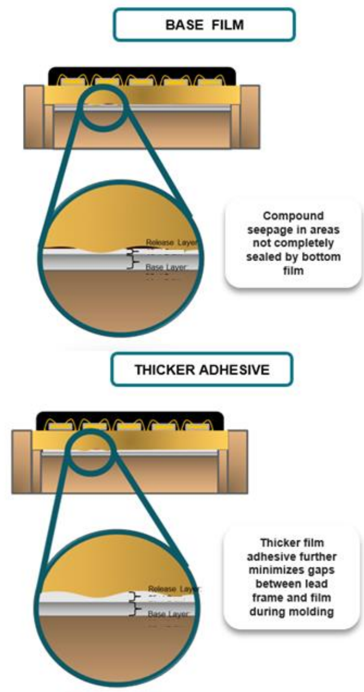


Figure 11. *Comparison between the base mold release film and mold release film with thicker adhesive.*

In this study two types of film from two existing suppliers were used (see **Table 2**). A total of 160 lots were used in this study. Units were subjected to automated visual inspection to quantify units with flashing and compare the performance of the two film types.

Table 3. *Comparison of Mold Flash Signatures after Mold and Deflash using Supplier A and Supplier B release films.*

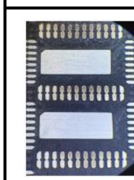
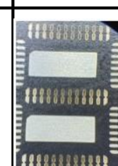
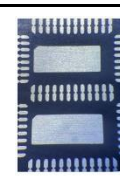
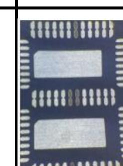
After Mold		**After Deflash**	
Supplier A	Supplier B	Supplier A	Supplier B
			

Table 3 illustrates the mold flash signature for each film after mold and deflash process.

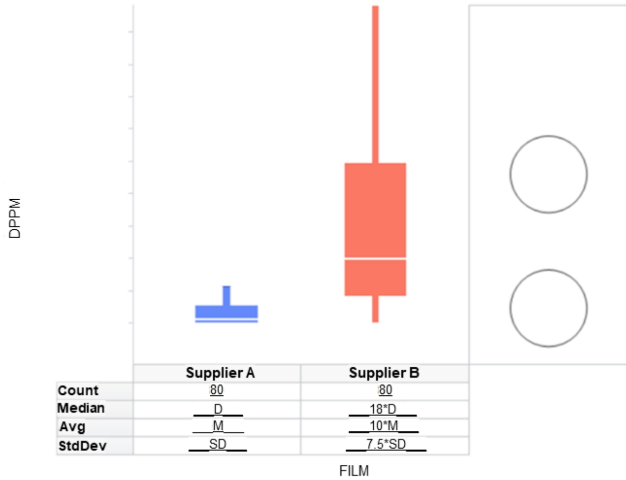


Figure 12. *Comparison of mold flash DPPM between Supplier A Film and Supplier Film.*

Figure 12 shows the mean mold flash DPPM of M and 10*M for Supplier A and Supplier B, respectively. Results were further analyzed statistically using the general factorial by one-way analysis of variance (ANOVA) at a significance level of 0.05.

One-way ANOVA results showed that there was a significant difference between the mold flash performance of Supplier A (*M*, *SD*) and Supplier B (*10*M*, *7.5*SD*) with p=2.37E-006.

Thicker release layer can provide better support or proper holding onto lead finger to prevent mold compound sip into bottom lead and film, hence reduces mold flash.[1]

4.4 Effectiveness Monitoring

With all these key actions combined to form the golden line from Wire Bond to Mold, the mold flash DPPM dropped by 70-90% as of writing. These already translated to <5% increase in the WLF yield (see **Figure 13**).

These solutions would also help increase productivity by 50% through reduction of chase tooling time by half. Significant productivity improvement for the production specialists was also observed due to the elimination of reject map guard band procedure with the decreasing mold flash rejection. For flip chip devices, these actions also helped minimize risk of solder crack and would further be eradicated upon full implementation of the slit-type bottom chase design.

In terms of savings, cost avoidance of thousands of dollars per year for vacuum pin replacement is expected across all WLF mold tools with the use of the new chase design. Moreover, about millions of dollars' worth of loss per year from scrap due to mold flashing would be eliminated through the golden line strategy and innovations.

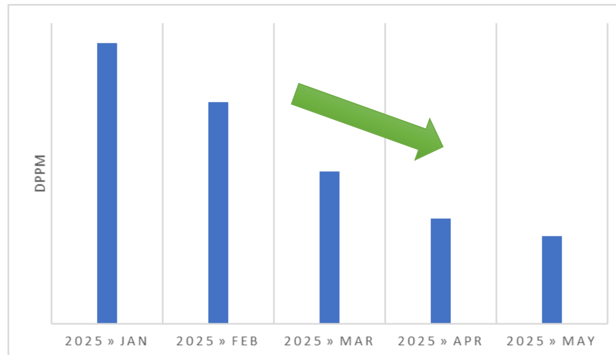


Figure 13. *Mold flash DPPM recovery from January 2025 to May 2025.*

5.0 CONCLUSION

The investigation identified three primary contributors to mold flash defects in WLF QFN assembly: the fulcrum effect from high tower inserts, unbalanced chase-to-pin planarity from vacuum pin-type chases, and insufficient mold release film coverage. Targeted interventions—including low/no tower insert restriction, the transition to slit-type mold chases, and the use of mold release film with improved adhesion—were implemented as part of a Golden Line strategy spanning Wire Bond and Mold processes.

These solutions, guided by lean principles and supported by data-driven analysis, significantly reduced mold flash defect rates and improved assembly yield by 2-5%. The success of this integrated approach underscores the critical role of root cause analysis, process standardization, and design optimization in advancing high-density semiconductor manufacturing.

6.0 RECOMMENDATIONS

It is highly recommended to follow through with the implementation and fan-out of the technologies and innovations discussed in this study. To reduce vertical flashing and to improve the vacuum performance during wire bonding, it is recommended to make use of the flat tower insert design. Existing heater block inserts with towers may be transformed to be flat either through rework or shimming which were previously discussed in this study.

The slit-type bottom mold chase design is also recommended for film-assisted molding processes. This improved design can eliminate periphery flashing caused by sinking or protruding vacuum pins and also features easy disassembly for accessibility and convenience during maintenance.

The use of mold release film with thicker adhesive is recommended as a strong containment action in the line, especially while the root causes of flashing are still being investigated or when the permanent solution requires more time to be implemented. The thicker film not only helps with the leads flashing signature from wire bonding, but it can generally provide a better cushion to seal the gap between the film and any form of nonplanarity on the strip. To address leads flashing straight from the source, it is still recommended to explore different bonding approaches and capillary designs to determine which would minimize stress during tail-cutting while still maintaining good adhesion of the wire on the leads, especially for larger wire diameters.

7.0 ACKNOWLEDGMENT

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9.0 ABOUT THE AUTHORS

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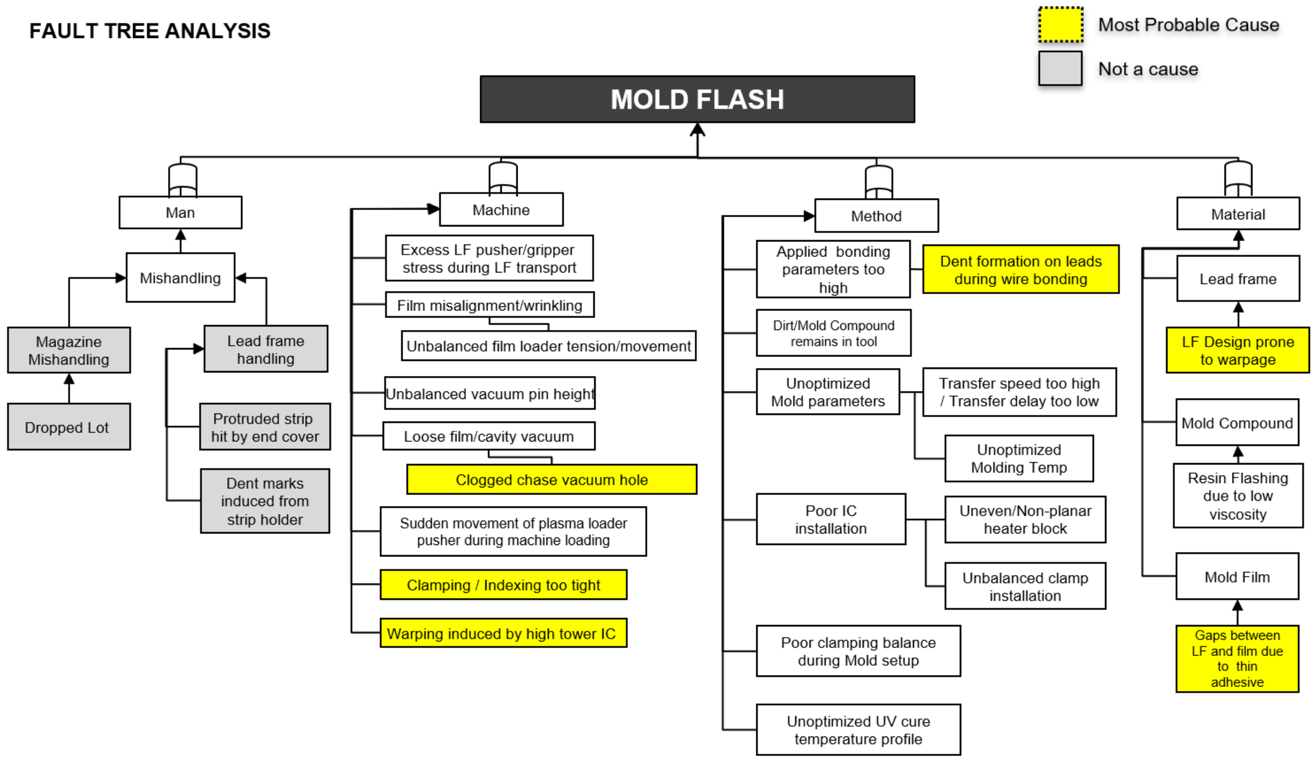
9.0 APPENDIX

FAULT TREE ANALYSIS



Appendix 1. *Fault Tree Analysis on man-, machine-, method-, and material-related causes of Mold Flashing.*

Splits	WB and Mold MC	Lead frame	Insert and Clamp	Wirebond Condition			Result	Remarks
				Indexed?	Die?	Wire?		
1	WB1234 ML5678	Bad LF PN (With Die)	-	No	Yes	No		No flashing
2	WB1234 ML5678	Good LF PN (Bare)	-	No	No	No		No flashing
3	WB1234 ML5678	Bad LF PN (With Die)	No Tower	Yes	Yes	No		Very light flashing on small areas
4	WB1234 ML5678	Good LF PN (With Die)	No Tower	Yes	Yes	No		No flashing
5	WB1234 ML5678	Bad LF PN (With Die)	With Tower	Yes	Yes	No		**Light flashing on small areas**
6	WB1234 ML5678	Good LF PN (With Die)	With Tower	Yes	Yes	No		No Flashing
7	WB1234 ML5678	Bad LF PN (With Die)	No Tower	Yes	Yes	Yes		Light flashing on small areas
8	WB1234 ML5678	Bad LF PN (With Die)	With Tower	Yes	Yes	Yes		**Heavy vertical flashing in center**

Appendix 2. *Results of mold flash DOE on varying wire bond designs and condition*