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Package Voids Elimination in Fragile Flip Chip System in Package Device

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Abstract— *The thin package outline and sensitivity to pressure due to its pillar structure, requires a well developed process in transfer mold packaging that will minimize package voids while ensuring device performance.*

This technical paper outlines the Define, Measure, Analyze, Implement, Control (DMAIC) method utilized in the development of the process. The methodology covers both detection and failure identification as per process mapping. With a very keen understanding of the package construction, actions were carefully validated to known rootcause for voids resulting to improved voids performance and reliable product quality.

Keywords— *Flipchip Package Voids.*

I. INTRODUCTION

1.1 Package Voids Detection at Customer

One problem encountered in the initial release of the module was reported by the customer during board mount assembly inspection. They detected package voids on the side of the device.

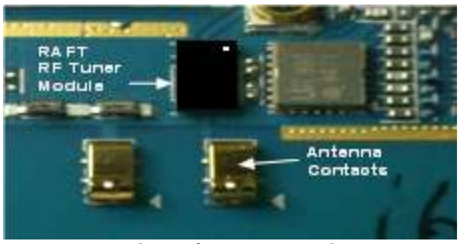

Fig. 1. Photo of Customer Application

Is a sensitive device wherein package voids can lead to exposure of the PTIC dice and other components to moisture that can possibly cause shorting on the PTIC die. The die which contain stacked capacitors in series can be affected by the ingress of moisture, changing its capacitance and thereby affecting its tuning function.

1.2 Assembly Yield Performance

Assembly yield trend was stable prior to the customer incident. After the detected problem was reported, an additional inspection to screen out side voids was implemented at assembly. Yield performance was monitored and was observed slightly lower than the yield target. Based from the assembly defect list, package voids is the highest number of defect.

1.3 Defect Phenomenon

Based from the defect signature from the customer complaint and visual inspection on singulated units, gross voids can be seen on the side by naked eye inspection, while voids on the marking lines can be seen under high magnification. Normal visual inspection is usually done on top and bottom of package by naked eye.


Fig. 2. Gross package voids on side view

1.4 Defect Characterization

Based from the strip mapping done, SCAT analysis revealed internal voids localized on airvent of affected strip. No external voids were seen on all inspected strips.

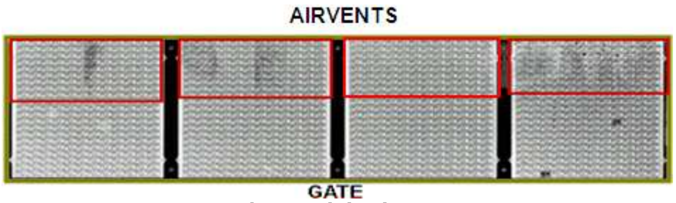

Fig. 3. Package voids localization on strip

II. REVIEW OF RELATED LITERATURE

2.1 Mold Filling Analysis for Flip chip / SIP

Based from the data on the technical paper, "Rheological Characterization and Full 3D Mold Flow Simulation in Multi-Die Stack CSP of Chip Array Packaging" by Min Woo Lee and co-authors from Amkor Korea, the elasticity of the epoxy molding compound is considered negligible if the degree of cure of the sample is low. Because they are only interested in the filling stage of encapsulation where the degree of cure is low enough, they neglect the elasticity of the fluid and thus assume the flow to be generalized Newtonian. The governing equations for current evaluation with epoxy molding compound melt flow in a mold array cavity during transfer molding are based on the basic conservation laws summarized by the Navier-Stokes equations found in literature [3]. These equations are typically embedded in simulation software programs. Full 3 dimensional meshes is generated to simulate the effect of center gate of the mold dispense mechanism. The center gate is the widest gate. The total number of finite element meshes used for full 3D model for current studies are

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about 700,000~900,000. The transfer time for mold filling process was 7.4 sec (pot and runner filling time = 3.4 sec and cavity filling time 4.0sec) with optimum ram speed profile control obtained from the mold process DOE.

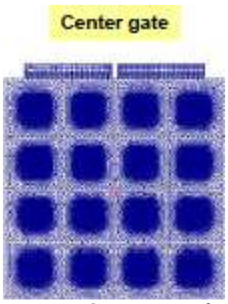


Fig. 4. Finite elements mesh generation for center gate type

As shown in Figure 5, this represents the time contour plots of the melt front advancement for current evaluations. For center gate type, the melt front is parallel to the gate, but the filling patterns are influenced by the stacked die. The flow retardation is occurred on the die top surface of stacked structure which induces the void trapping phenomena along the final filling area of package edge (ref. Figure 5-a).

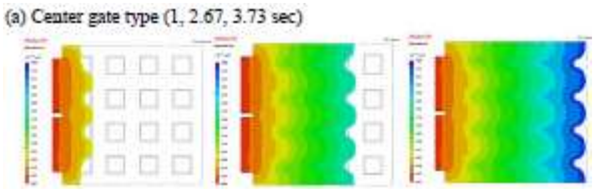


Fig. 5. Melt front advancement of evaluated gate type

As shown in Figure 6, the short shots of the mold process results for current evaluation of center gate type (1) which indicate that the melt front advancement patterns are similar to the simulated contour shapes.

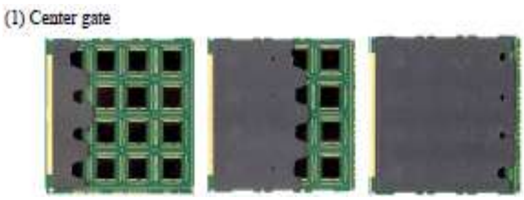


Fig. 6. Short shot of experimental results

As shown Figure 7, the simulated case studies and actual mold void trapping shapes at the final filling stage of the mold filling process. The simulated results as shown in figure 7-a is bottom side view (substrate interface) with 99% mold filling cases of void trapping occurred position for center gate and corner gate respectively. As shown in Figure 7-b, the exemplary optical microscope pictures of the actual incomplete mold void occurred at mold topside, where the gold wires are exposed due to incomplete mold.

The mold void or incomplete mold phenomena are closely related to the flow retardation in the relatively narrow space such as thin mold gap between mold chase and die top surface with repetitive structures of mold array patterns.

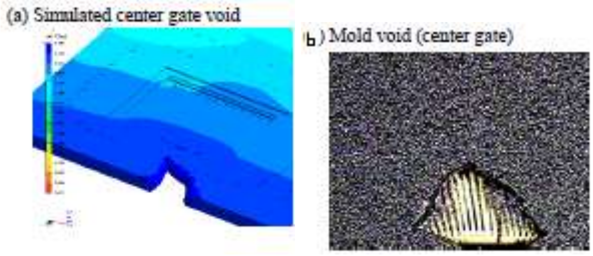
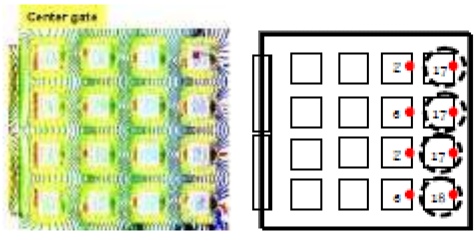


Fig. 7. The comparison of the simulated and actual mold voids

As shown in Figure 8, the flow time contour plotting for each case and estimated possible void occurring area (a) and the number of the void acquired from experimental results (b). The void occurring positions and the flow retarding areas are quite similar to that of the experimental void positions where the contour lines are very close to each other.



(a) (b)

Fig. 8. (a) Mold filling time contour plotting (prediction) and (b) the actual mold void position through experiments (about 200 unit tests for each gate type)

As shown in Figure 9, the thermosetting conversion contour. The flow retardation in the die overhang area of same die stacking near the gate is getting more severe as the gate type is changed to center to corner.

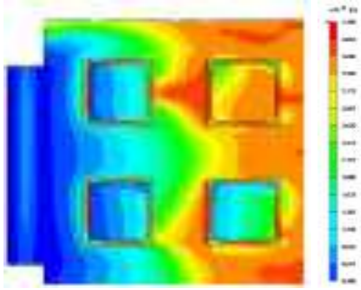


Fig. 9. Thermosetting conversion contour

The flow induced shear stress contours of the each gate type at the final filling stage are shown as shown in figure 10 below. The standard center gate shows that the shear stress distributions are relatively homogeneous.

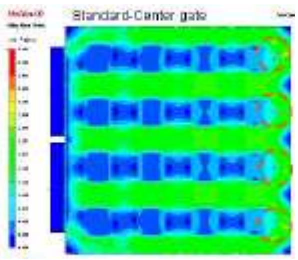


Fig. 10. The flow induced shear stress fields of the gate

As shown in Figure 11, the velocity vector profiles in mold array for each gate type. Similar to the shear stress and pressure cases, the mold flow velocity is drastically increased near to the gate and final outlet as the gate type is changed from center to corner gate, while the center gate case has relatively uniform velocity vector values. But the corner gate, the unbalanced velocity distribution may cause the severe wire sweeping near to the gates and final mold filling zone.

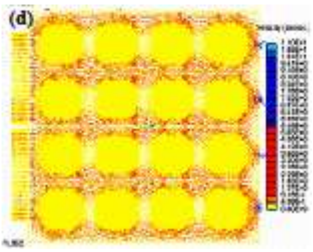


Fig. 11. The velocity vector field of simulated EMC melt corner gate

III. EXPERIMENTAL

3.1 Package Voids Non-Detection Validation

Detection control was revisited to explain why package voids were not detected at manufacturing line. In assembly, mold visual inspection is 100% under naked eye and SCAT monitoring is every start of shift to check for internal voids. At assembly final visual inspection, lot is subject to 100% top and bottom inspection. At finish, lot is subject to 100% automatic inspection machine also for top and bottom defect only. With these controls, package side voids can possibly escape.

In lieu to this, inspection capability for package side voids for both Assembly and Finish was initiated to screen 100% side voids using the specification criteria of 300um. Correlation of side voids dimension was done to check which inspection machine is capable for the accurate screening of the defect.

3.2 Failure Mechanism for Package Voids

Based from the defect signature, possible cause of package voids is due to insufficient mold compound packing which manifests localization on airvent same as the study previously discussed in section 2.2.

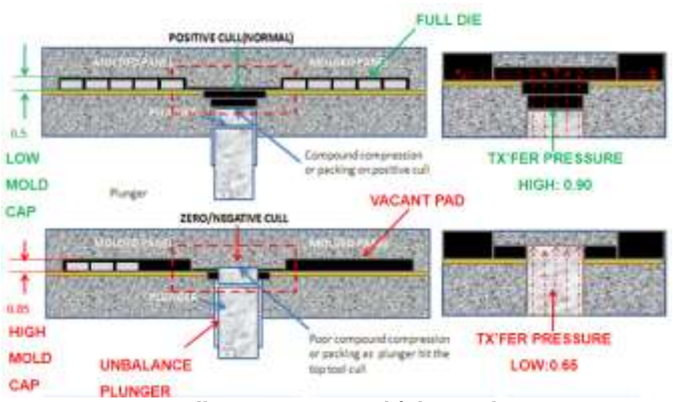


Fig. 12. Illustration on potential failure mechanism

3.3 Fault Tree Diagram for Package Voids

Based from the fault tree, there are several potential root causes of package voids which were identified as a result of brainstorming. The potential causes were then subjected to a validation process which led to the confirmation of our red X and pink X. For our pink X, manual molding process and plunger abnormality were identified and were immediately addressed and controlled. Under red X, 3 causes were identified, namely; Low transfer pressure, high die vacancy on lots and insufficient compound volume leading to negative culls as our real rootcause.

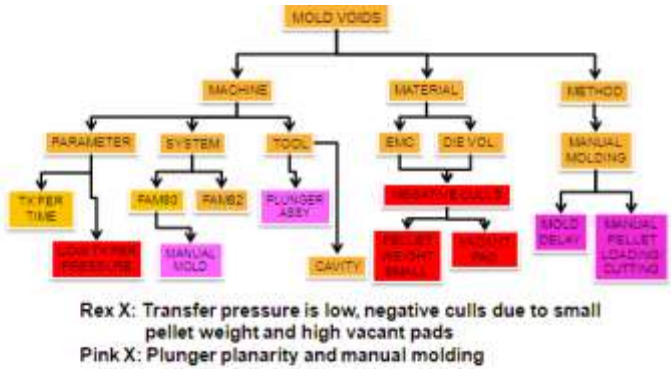


Fig. 13. Package voids fault tree diagram

3.4 Rootcause Validation

Based from the validation matrix, low transfer pressure, insufficient compound volume and high die vacancy are the true cause. For mold delay, this was already addressed by running on machine capable for automold.

Table 1. Validation Matrix for Package voids

Potential Rootcause	Method of Validation	Evaluation	Result	Remarks
Plunger Assy	Visual and functional	Check for stuck up or worn-out parts	Transfer profile shows no abnormality	NTC
Mold Temperature	Pyrometer	Check machine for temperature not within specs	Passed, machine has alarm for mold temp	NTC
Small Pellet weight against mold requirement	Mold cap thickness	Compare mold cap per package type	Mold cap for STRAFT is highest at 0.85 using same mold compound weight of 7.3g	TC
Vacant pad	SCAT / Visual	Compare lot with full die and with vacant pad	High PPM for lots with vacant pad	TC
Transfer pressure is low	SCAT / Visual	Compare parameter with other pkgs	Low transfer pressure for STRAFT	TC
Mold delay	Timer	Measure actual pellet preheat using manual mold	Actual preheat vary from 4 to 8sec vs. 0-5 sec specs at manual mold	TC

3.4.1 High die vacancy

For high die vacancy, an experiment was generated to check the mold voids rejection rate via SCAT and side inspection for strips with varying die vacancy. The SCAT analysis will also reveal the voids mapping within a strip per die population.

3.4.2 Insufficient mold compound volume

For mold compound volume insufficiency, comparison of device to other packages with respect to mold cap dimension to check for difference that can influence package voiding will be evaluated. Also the resulting mold cull will be considered as insufficiency can be directly manifested by the resulting cull.

3.4.3 Transfer pressure is low

For transfer pressure is low, we will first understand how the mold parts functions to identify the machine requirement for transfer pressure and to compute for the appropriate transfer pressure to achieve zero voids.

Also, full reliability will be conducted on devices using split runs of 0.65tons and 0.90tons transfer pressure to check for potential risk on copper pillar quality. Reliability tests such as MSLA (2&3), 500TMCL, 96 hrs uHAST and 168 hrs HTS are include in this assessment.

IV. Results and Discussion

4.1 Assembly vs. Finish Inspection Machine Correlation by Side Voids Length

Based from statistical analysis, correlation, R^2, value for Finish inspection machine is higher at 83% against the Assembly inspection machine at 65%. Note that acceptable R^2 to have good correlation is 70%.

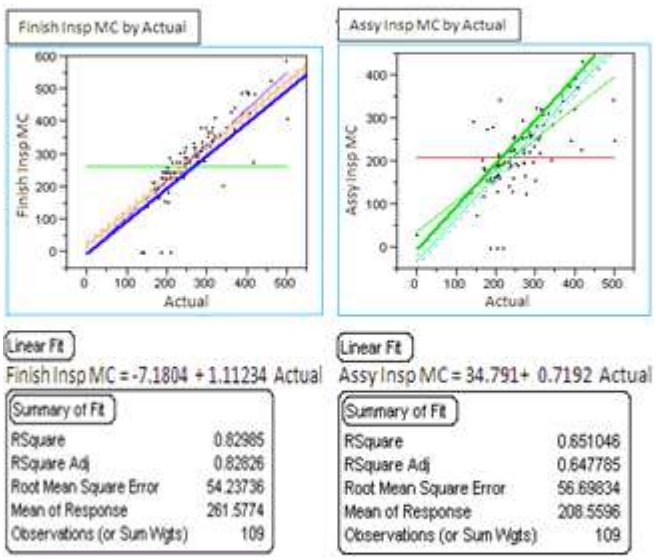
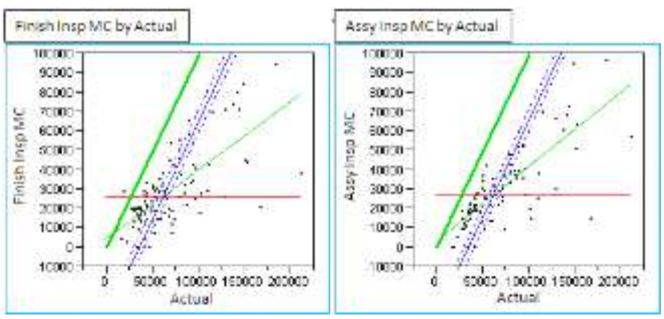


Fig. 14. Correlation data for side voids length

4.1.1 Assembly vs. Finish Inspection Machine Correlation by Side Voids Area

Based from statistical analysis, correlation, R^2, value for Finish inspection machine is lower at 56% against the Assembly inspection machine at 66%. Note that both are below the acceptable R^2 to have good correlation of 70%.



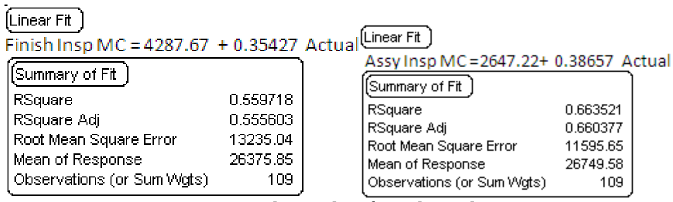


Fig. 15. Correlation data for side voids area

It was decided based from the correlation data to use length as the parameter to use for side voids screening on inspection machine due to higher correlation and it also aligns to the package voids criteria which is defined in length. As expected, significant increase in package voids rejection rate was observed during the implementation of machine side inspection capability both at Assembly and Finish. This inspection method resulted to zero customer complaint on package voids.

Since Finish inspection machine has higher correlation value, it was decided to discontinue assembly inspection machine processing after the implementation of all corrective action.

4.2 High Die Vacancy

It was verified through SCAT that it is encountering higher rejection of package voids as vacant pad on strip increases.

Table 2. Strip quantity vs. package voids rejection rate

	QTY IN	VOIDS	% Reject rate	Remarks
Strip # 1 Dummy strip	996	87	8.73%	Strip # 1 full QTY paired with dummy strip (vacant substrate)
Strip # 2 Strip # 3	1998	0	0%	Both strips full QTY
Strip # 4 Strip # 5	1997	0	0%	Both strips full QTY
Strip # 6 Strip # 7	1837	12	0.65%	Strip # 6 full QTY / Strip # 7 with 66% vacant pad on last panel

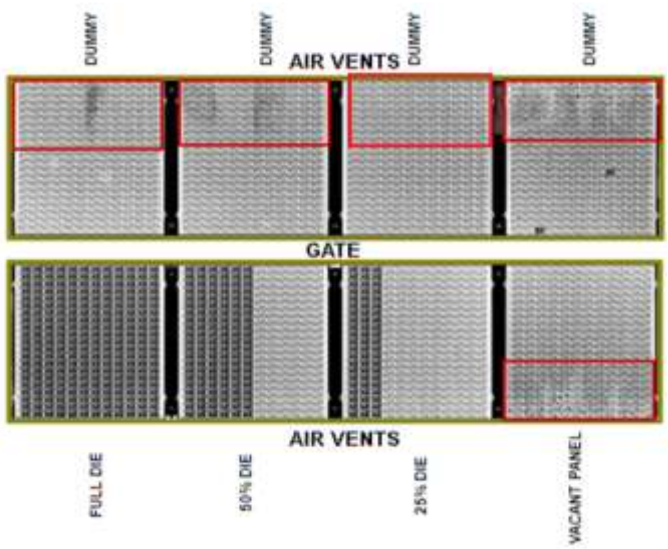


Fig. 16. SCAT response to different vacant pad quantity

With the limited availability of PTICs from Fab, all dies available are built resulting to an uncontrolled lot quantity leading to different amount of vacancy on strip.

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With the package voids localized at airvent side, assessment was performed to check the capability of mounting the components away from the airvent. Component mounter was proven to be capable of placing dice in a horizontal direction with no adverse effect to UPH and was already implemented

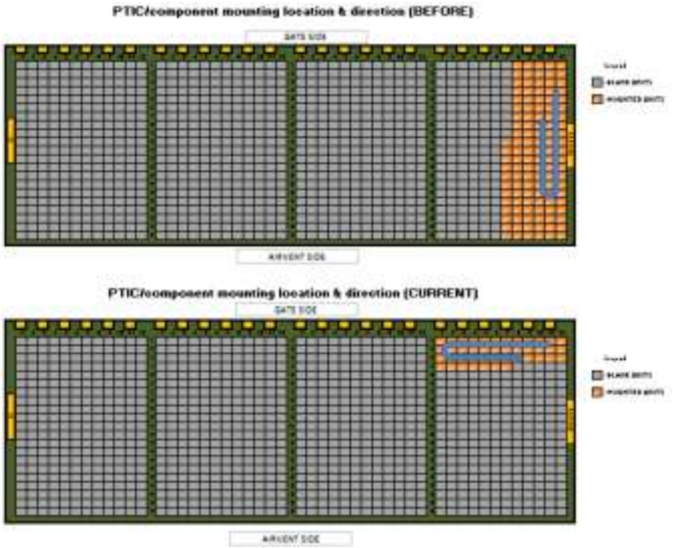

Fig. 17. Comparison of die placement

4.3 Insufficient Mold Compound Volume

Mold compound size of 7.3g used is the same size used for other packages. However the package thickness of is the highest at 0.85mm as compared to the maximum 0.65mm for other packages which will require higher mold compound volume. This leads to negative or zero culls resulting to package voids as plunger pressure is not transferred to the material but most are lost to the top cull block.(see fig.12 failure mechanism)

Further observation revealed that the resulting mold cull shifts from negative to zero center culls as vacancy increases.

Fig. 18. Good culls vs. Zero culls

A computation was made to define the required pellet weight for all devices and arrived at a pellet weight of 8.5g. This was consulted with mold compound supplier if manufacturable as increasing the pellet weight at a 14mm diameter will elongate the pellet and is susceptible to broken pellets. It was confirmed by supplier that they are capable to manufacture 8.5g and was further verified through supplier testing and incoming quality check of compound in Calamba wherein no broken pellets were seen on several batches.

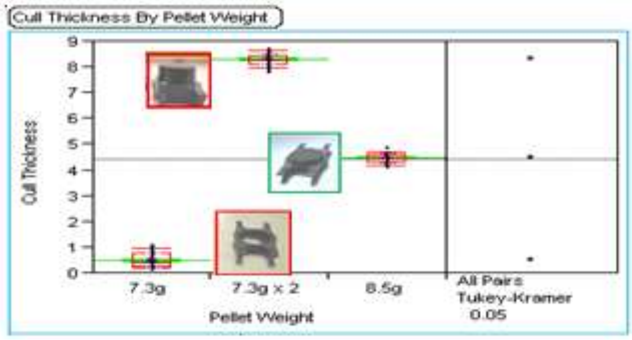

Fig. 19. Boxplot of cull thickness per pellet weight

4.4 Transfer Pressure is Low

Device was qualified using 0.65 tons as its transfer pressure which was based from the parameter used from previously qualified SIP products as compared to the minimum of 0.8 tons used for HVQFN and BGA packages.

A study was conducted to identify the required minimum transfer pressure based on machine requirement. One of the main equipment part that influences transfer pressure is the plunger spring. The purpose of plunger spring is to absorb the differences of weight, height and density of each pellet as illustrated in fig. 20. By applying Hooke's Law we can compute for the spring force as shown in fig. 21.

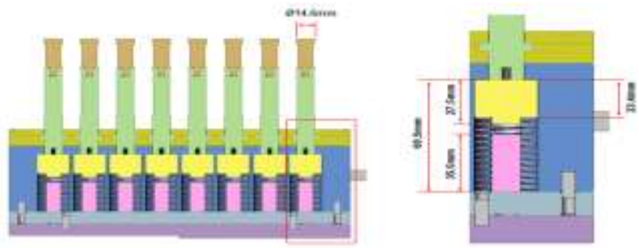

Fig. 20. Structure of transfer plunger

If the transfer pressure is below 0.76tons, the spring will not be pressed and it will lead to package voids
Spring Size : □25mm x 50mm
Spring Constant : 24.5 Kgf/mm
Compression of Spring: 3.9mm

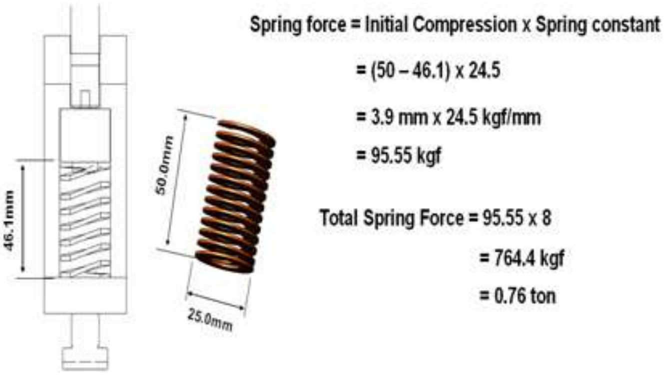

Fig. 21. Computation of spring force

Transfer pressure can be calculated using the formula below:
Transfer Pressure = Plunger tip Area(A) x Material Pressure (MP)

Plunger tip Area = □D^2 / 4 x no. of plungers

Material pressure is normally provided by compound supplier or customer requirement which is usually at 1000-1700 psi (0.070-0.12ton) for semiconductor.

Therefore a transfer pressure of 0.65tons is not recommended as it is below the minimum spring force requirement of 0.76ton.

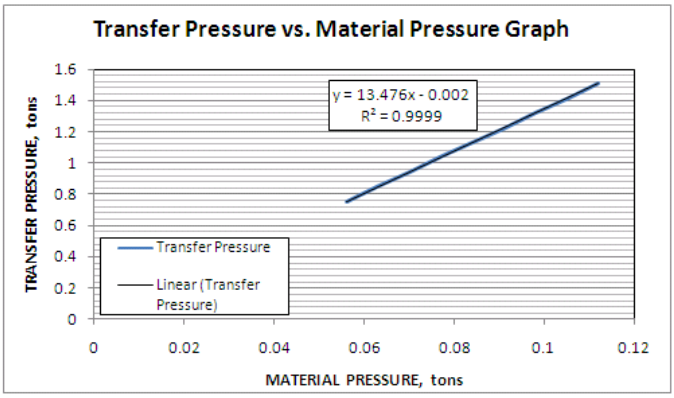

Fig. 22. Transfer pressure vs. material pressure Graph

However, copper and aluminum have an electrochemical potential difference; they promote galvanic corrosion when combined. Copper pillars in a PTIC are deposited on top of aluminum so there is already risk of weak pillars.

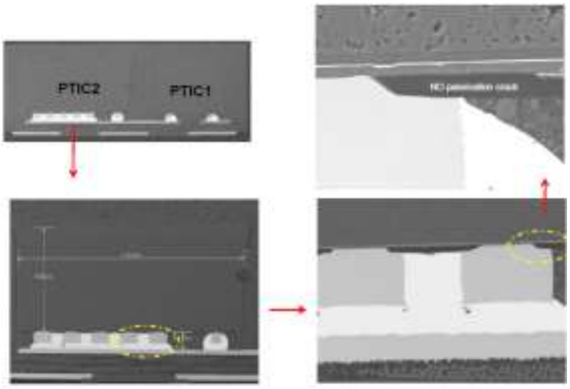

Fig. 23. Cross section showing pillar structure

Increasing the transfer pressure from 0.65 tons to 0.90tons could impose a risk on the pillar quality when mold compound passes through the pillars during molding as shown below.

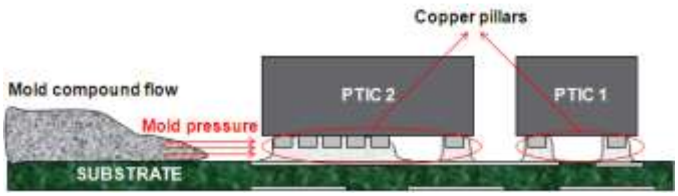

Fig. 24. Illustration of mold flow on copper pillars

With the machine minimum pressure calculation of 0.76tons, which is above the current transfer pressure of 0.65tons used, material pressure specification was requested from the mold supplier. This will be needed to compute for the transfer pressure to be used for package voids validation. Computed transfer pressure was 0.94tons while it was decided to use 0.90tons during evaluation.

Material Pressure: 1000psi or 70 kgf/cm^2 or 0.07tons

Plunger tip Area = □D^2 / 4 x no. of plungers

= □□□□□□□mm)^2/4 x 8

= 13.44 mm^2

Transfer Pressure = Plunger tip Area(A) x Material Pressure (MP)

= 70 kgf/cm^2 x 13.44mm^2

= 941 kgf/cm^2 or 0.94tons

4.4.1 Reliability result of high transfer pressure

Full reliability was conducted on devices using split runs of 0.65tons and 0.90tons transfer pressure. Data shows passing result using 0.90tons. Reliability tests such as MSLA (2&3), 500TMCL, 96 hrs uHAST and 168 hrs HTS were all completed and passed.

4.5 Package Voids ppm Trend

The impact of the improvement actions lead to the reduction of package voids by 94%.

For the transfer pressure of 0.9tons, qualification data and initial production monitoring (IPM) shows zero voids. However due to the several device variants, the Division decided to do full qualification of the change to all variants which will be completed.

V. Conclusion

We conclude therefore that package voids can be reduced significantly with the increase in transfer pressure to 0.90tons which aligns to the machine transfer pressure requirement without affecting the copper pillar quality. Increase in pellet weight from 7.3g to 8.5g also made the process robust to die volumetric difference of production lots due to varying lot quantity.

VI. Recommendations

It is recommended to update our Corporate Packaging Assembly (CPA) specification to include the cull assessment during early stage of the qualification of incoming new packages.

With the significant improvement of package voids, external visual inspection can be reduced to normal visual inspection instead of 100% side voids inspection by inspection machine at assembly while retaining Finish machine inspection without having the risk of escapee which is a potential customer complaint.

Acknowledgment

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