DEEP-DIVE INVESTIGATION ON PAD DISCOLORATION ISSUE IN OPTICAL SENSING DEVICE

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ABSTRACT

Pad discoloration has been the major issue encountered in one device in STMicroelectronics Inc. It started to manifest during Engineering phase and continued to manifest until mass production. This paper discusses the implementation of the Plan-Do-Check-Act (PDCA) which resulted to a structured and comprehensive analysis on the different factors that influence the flow of resin bleed-out (RBO) towards the LGA (Land Grid Array) pad of the substrate.

Thorough failure analysis and validation of results were undertaken to be able to identify the root cause. It was proven that several factors may contribute to the flow of RBO towards the LGA pad of the unit but in this case, the root cause identified is by far different from what is already known. With the deep dive failure analysis done, the team were able to pin down the root cause of the resin bleed out issue which is not the usual root cause commonly seen in the semiconductor industry 8D reports for RBO.

1. 0 INTRODUCTION

Addressing the Voice of Customer (VOC) as one of the top priorities of STMicroelectronics Inc., the need to focus on detractors to meet yield target must be given attention. Based on the yield performance in Fig 1, the yield remained below the 99.12% target.

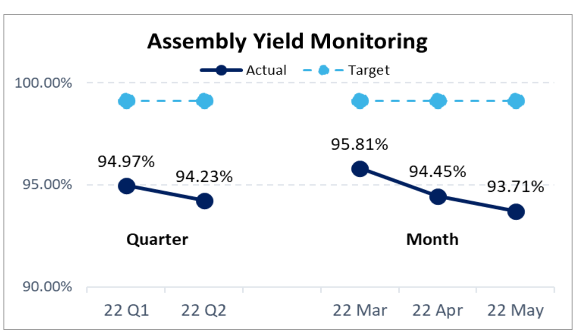


Fig 1. Yield monitoring

Among the top 10 detractors, the highest contributor is the pad discoloration due to RBO as shown in Fig. 2. It has been the major issue encountered in one device in OPS2. It started to manifest during Engineering phase and continued until mass production.

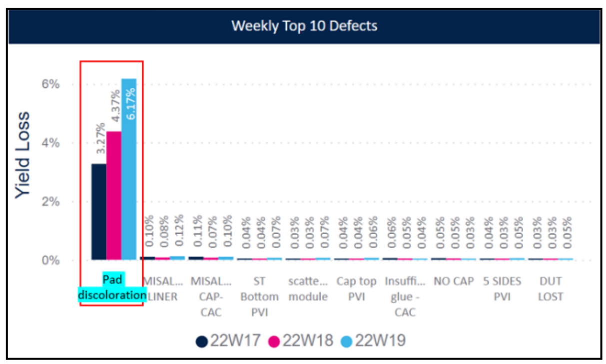


Fig 2. Weekly Top 10 Defects

Further investigation showed that among the two substrate suppliers, only Supplier 2 contributed to low yielding lots which affected the yield target as per Fig 3.

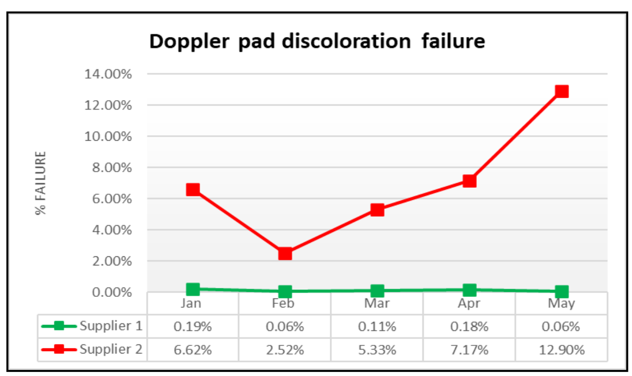


Fig 3. Doppler Pad Discoloration Monitoring

1.1 Pad discoloration physical observation

Figure 4 shows the resin bleed out mechanism that caused the pad discoloration. After epoxy dispense on the substrate, the cap will be attached causing the glue to overflow at the bond line & cap interface. After which, the epoxy resin will continue to flow along the substrate edge down to the prepreg material at LGA (Land Grid Array) solder mask opening until it reaches the gold pad.

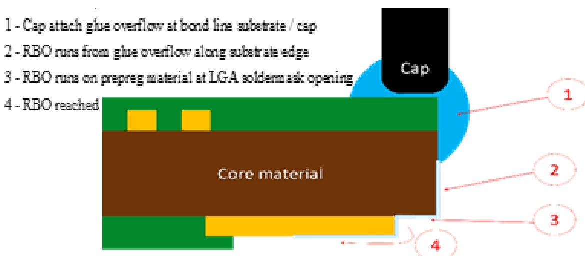


Fig 4. Resin Bleed Out mechanism

1.2 Pad Identification and sample defect manifestation

P2/P6 side of the substrate are NSMD (non-soldermask defined) which is known to have RBO during processing.
P4/P8 side of the substrate are SMD (soldermask defined) which have zero occurrence of RBO on LGA pad.

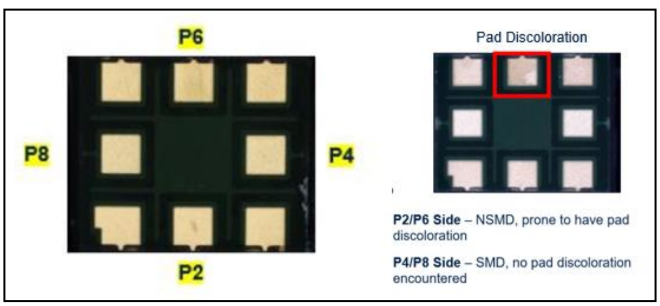


Fig 5. Doppler Pad Discoloration Monitoring

This paper aims to deep dive on substrate construction that could influence the RBO towards the LGA pad. There were several factors identified that pertain to man, machine, material, method and environment which will be described using the Fishbone analysis.

2. 0 REVIEW OF RELATED WORK

Resin Bleed Out is a surface phenomenon whereby fractions of the organic resin or reactive diluents migrate along the surface of the substrate or up the side of the semiconductor chip due to surface energy difference between the resin & the substrate. [1]

Die attach pastes, which consist of resin, curing agent, catalyst, filler and additives, have been extensively used to attach die onto lead frames (or substrates) in various electronic packages. One of the issues commonly encountered during package assembly is Resin bleed-out (RBO), or epoxy bleed out (EBO).

RBO is the separation of some formulation ingredients in the paste from the bulk paste. Depending on the die attach paste formulation and lead frame (or substrate) surface chemistry and morphology, bleeding ingredients can be solvents, reactive diluents, low-molecular-weight resins, catalysts, and additives like adhesion promoter. Resin bleed out tends to occur on high energy surfaces such as metal leadframes without any organic coating. In particular, if plasma cleaning is utilized to remove the contaminates prior to assembly, bleeding issue may become more pronounced due to the increase in surface energy. Bleed-out can occur once die attach paste are dispensed on to the leadframes or during thermal process. As microelectronics continue to move towards smaller factor, higher reliability and higher performance, control of RBO becomes increasingly critical for packages where there is a very little clearance between die and die pad edge, or between one die and another in multi-chip modules (MCMs).

3.0 METHODOLOGY

3.1. Identification of Problem

Using fishbone diagram, several potential causes on man, machine, method, material, and environment were identified and validated one by one.

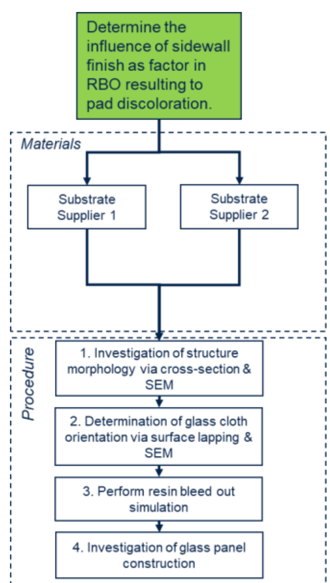


Fig 6. Experimental Procedure.

3.2. Validation of Sidewall Morphology as Factor on Pad Discoloration

Two substrate suppliers were compared to validate the influence of sidewall structure on the progression of RBO causing pad discoloration. Fig 6 shows the methodology applied in this paper.

4.0 RESULTS AND DISCUSSION

From the fishbone diagram (Appendix A), the potential root cause identified is related to the substrate material that needs further investigation. Table 1 shows the validations made for the substrate material. Based on assessment, glue flow is influenced by sidewall morphology.

Table 1. Summary of Validations for Materials

#	Process Mapping/Validation and DOE	Status/ Result Summary	Status	Assessment
1	Checking of Cap Placement/Cap Overhang, POA	Comparable data between affected and good units in terms of pad discoloration	Done	Not a factor
2	Checking of glue overflow at the side of the module	Large glue overflow observed in CRB-0A lot (5%FR) Comparable glue overflow observed in CRB-1A (20%FR)	Done	Glue flow is influenced by sidewall of the module.
3	Checking of BLT on perimeters of the module	Comparable NC glue BLT between affected and good units in terms of pad discoloration	Done	Not a factor
4	Stiffener Mapping of Rejects	Heat map shows no specific location on stiffener	Done	Not a factor
5	Substrate Mapping of Rejects	Heat map shows more reject on channel 1 cut line	Done	Cap resin not detected in FTIR
6	VI check stiffener skeleton on laminate tape any contamination	No glue residue on the laminate tape, SM higher than the pad.	Done	Not a factor
7	Measure defect modules subs XY dimension and cap placement direction.	No significant difference of Sensor XY PBO data of affected lots with LGA pad discoloration and good lots	Done	Not a factor
8	SEM / EDX on LGA pad area with discoloration and without discoloration	EDX shows aluminum content on LGA pad area with discoloration suggesting glue resin deposition	Done	Not a factor
9	SEM / EDX on substrate sidewall	EDX shows aluminum content on the sidewall of substrate below the glue overflow	Done	Not a factor
10	SEM / EDX on pre-preg / core material	Observed fiber orientation towards LGA pad is the main differentiator between two Suppliers. This contributed to the sidewall morphology weakness found in Supplier 1.	Done	Main Factor
11	Retrieval of oven profile during curing of affected lots with LGA pad discoloration	No abnormality on the cap oven curing profile during processing of lots with LGA pad discoloration	Done	Not a factor
12	On off validation on KCC 12um Cu foil using POR and V pattern epoxy dispensing (DOE)	Validated not a contributor, similar discoloration occurred.	Done	Not a factor
13	On/Off Validation using same material of PP (Pre-preg) batch/lot from the Sub-Supplier of Suppliers 1 and 2. (DOE)	Observed occurrence of pad discoloration for both Suppliers when using same source of PP material site from Sub-Supplier	Done	Main Factor

4.1. Investigation of sidewall morphology via cross-section & SEM

Fig. 7 shows the comparison of sidewall morphologies. Based on the SEM (Scanning Electron Microscope) images, the sidewall of Supplier 1 is relatively rougher than Supplier 2. To validate the condition of the layers, both Pad 2 (NSMD) and Pad 4 (SMD) sides were cross-sectioned. The sample SEM images of before and after cross-section are shown in Fig. 8.

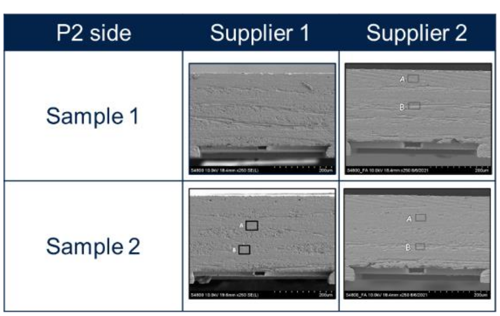


Fig 7. Morphology of Supplier 1 & 2 substrate materials at P2 side.

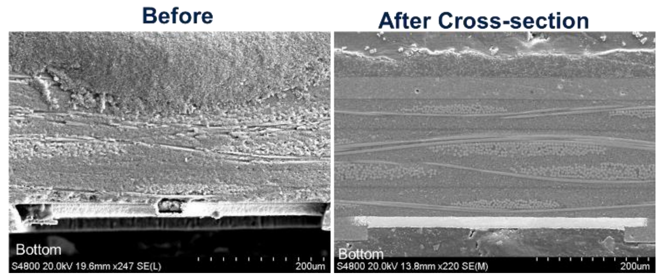


Fig 8. SEM image of the side wall before and after cross-section. Glass fibers are visible after the cut.

Fig 9 shows the SEM images of P2 side cross-section. Good units (w/o discoloration) and Reject units (w/ discoloration) were compared. It was noticed that Supplier 2 have higher density of glass fibers compared to Supplier 1.

The SEM images of P4 side cross-section are presented in Fig 10. A change in glass fiber density was observed; Supplier 1 now has higher glass fiber density compared to Supplier 2 at P4 side. In addition, the horizontal fibers in Supplier 2 appeared to be wave like as compared to Supplier 1 in P4 side. This wave-like condition is present also in Supplier 1 P2 side.

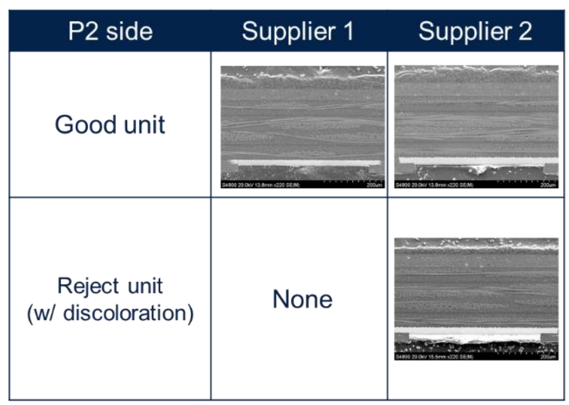


Fig 9. Cross-sectioned sidewall at P2 Side.

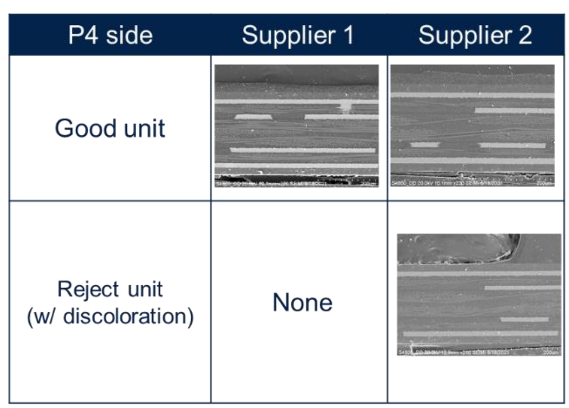


Fig 10. Cross-sectioned sidewall at P4 Side.

4.2. Determination of glass cloth orientation via surface lapping & SEM

To verify the glass cloth orientation, parallel lapping was carefully conducted on the samples. Fig 11 shows the location of the parallel cuts. The SEM images after this activity is shown in Fig 12.

Based on the result, there is a significant difference between the glass cloth orientation of the substrates. Supplier 1 has narrower vertical bundles while Supplier 2 has narrower horizontal bundles. This was verified also on the bundle width measurement shown in Fig 15. This difference played a key role in the morphologies of both substrates. The narrow vertical bundle at Supplier 1 produced a lower density of fibers and wavy-like appearance on the side wall, which may have helped to make the sidewall rougher and slow down the resin bleed out at P2 and P6 sides.

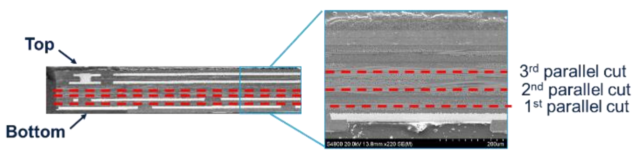


Fig 11. Location of the parallel cut on the substrate sample.

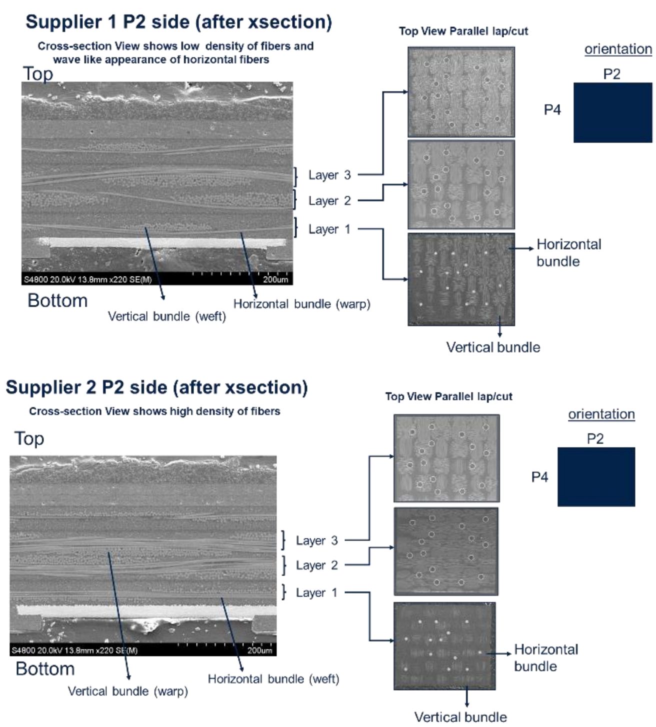


Fig 12. Glass fiber orientations for Supplier 1 and Supplier 2.

4.3. Resin Bleed Out Simulation

Simulation activity for resin bleed out at P2 and P4 sides were conducted by dropping a glue on the substrate then stage the sample for 12H.

Based on the results below, resin bleed travels slower at Supplier 1 (wave like fiber) than Supplier 2 (high dense fiber) at P2 side.

At P4 side, resin bleed travels faster at Supplier 1 (high dense fiber side) compared to Supplier 2 (wave like fiber side).

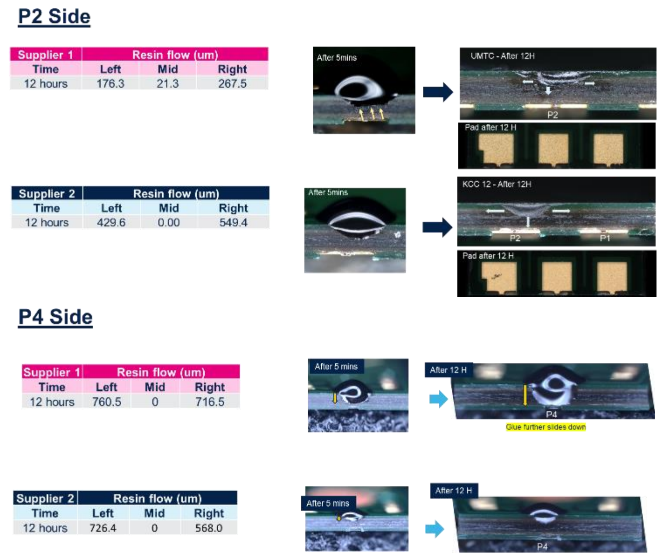


Fig 13. Simulation of RBO at P2 and P4 sides.

4.4. Investigation of Glass Panel Construction

Glass cloth consist of woven fibers called warp and weft. Weft is the horizontal yarn which is being woven to the vertical yarn called warp.

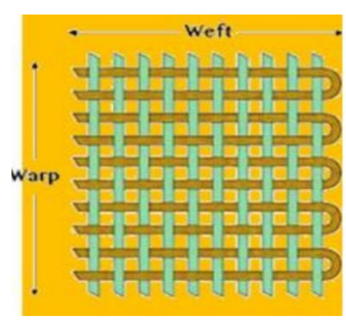
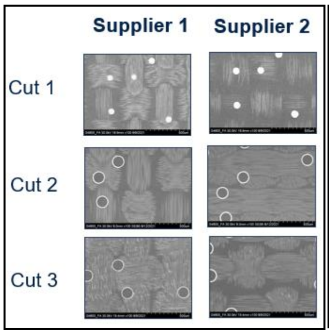


Fig 14. Warp & Weft weave on the substrate panel.

The parallel cut was done in several samples from both Supplier 1 and Supplier 2 to be able to measure and compare the bundle width with respect to orientation. Based on the results:

- Supplier 2 have relatively wider warp bundle width compared to Supplier 1.
- Supplier 2 have smaller weft bundle width compared to Supplier 1.
- Based on this data, considering they have the same source of fiber cloth, we can deduce that Supplier 1 is 90 degree rotated. This rotation determined the difference in morphology of the side wall.



Warp or vertical strand

Vertical	Supplier 1	Supplier 2
Cut 1	204um	334um
Cut 2	290um	374um
Cut 3	320um	438um

Weft or horizontal strand

Horizontal	Supplier 1	Supplier 2
Cut 1	305um	264um
Cut 2	416um	319um
Cut 3	422um	345um

5.0 CONCLUSION

From this study, it was proven that:

1. Pad discoloration is a result of resin bleed out (RBO) reaching the metal pad due to glue flow out. This metal pad is NSMD (Non-solder mask defined). Glue flow out on the sidewall is influenced by the condition of the roughness/ morphology.
2. Side wall's morphology varies depending on the Pre-Preg/Core material's "warp & weft" orientation/direction in the glass cloth material.

6.0 RECOMMENDATIONS

This study aims to share the learning of another root cause, Pre-Preg (PP) material construction, that may contribute to the RBO which is not common in the industry's existing FMEA (Failure Mode and Effect Analysis).

The authors recommend to consider this learning in the design of the substrate's LGA pad (SMD and NSMD) with respect to PP construction.

Fiber cloth orientation must be considered, likewise, during substrate process design when doing the device qualification.

7.0 ACKNOWLEDGMENT

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8.0 REFERENCES

1. M. Capili, International Research Journal of Advanced Engineering and Science ISSN (Online): 2455-9024

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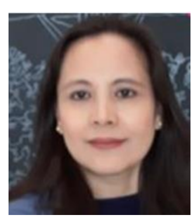

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Appendix A- Fish Bone Diagram