LATEST TECHNOLOGIES OF EPOXY MOLDING COMPOUND (EMC) FOR FO-WLP

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Abstract

FO-WLP is used for RF etc. for mobile as a package excellent in low profile, low warpage, cost reduction, electric performance etc. and this market is expanding since it began to be used in Application processer (AP) in 2016. It is expected that adoption to AP for mobile will continue to grow and further expansion to other products is also expected.

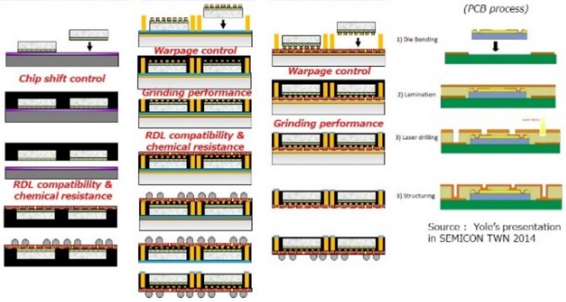
Meanwhile, Epoxy molding compound (EMC) for FO-WLP is required to have functions not found in EMC for low-end packages. For example, since the molding area is large and the molding thickness is thin, if a conventional EMC is used, the warpage becomes large after curing and it cannot proceed to the subsequent process. In order to control warpage after curing, it is important to reduce cure shrinkage of EMC. In addition, in order to fill completely the gap between flip chip bumps of large size chip, control of filler size, melt viscosity etc. is more severely required.

Key words

O-WLP, EMC, warpage, MUF, RDL

Introduction

FO-WLP uses epoxy molding compound to create the fun-out part. Currently, there are some processes to create FO-WLP. Chip 1st and face-down process is legacy process which is applied for eWLB. Chip 1st and face-up process includes grinding process of cured mold surface. Re-distribution layer(RDL) 1st (sometimes it is called chip last) process requires molding underfill(MUF) of bumping area of flip chip. As for panel level packaging(PLP), both compression and vacumm lamination are applied. Thus, depending on the process, different type material is required. (Figure 1)



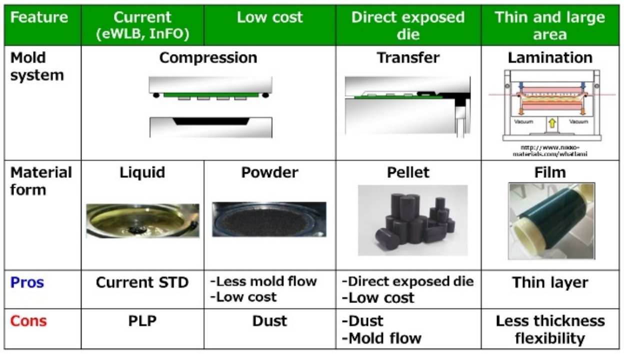
Source : Yole's presentation in SEMICON TWN 2014

Figure 1. Various FO-WLP process.

METHODLOGY

Mold system and material

Most of FO-WLP use compression mold system, and both liquid and powder type EMC are applicable for this mold system. Especially, liquid type EMC has been standard material of FO-WLP since eWLB released to the market, because it had less concern for dust in the clean room. However, recently, dust control by mold system and clean room layout is much improved, so, powder type EMC is getting popular, because it has technical and costly advantages. As shown in (Table 1), powder type EMC is not only low cost, but also contributes to total cost down by energy saving, because powder type EMC has longer shelf and floor life under milder condition. Besides that, powder type EMC can provide clean mold surface thanks to less mold flow, and no despensing issue from syringe like liquid type, even though it icludes very fine filler. It is big advantage for advanced FO-WLP including fine line and space(L/S) and very narrow gap, because such EMC need fine filler which generally causes high viscosity



Feature	Current (eWLB, InFO)	Low cost	Direct exposed die	Thin and large area
Mold system	Compression		Transfer	Lamination http://www.nano-materials.com/whatlami
Material form	Liquid	Powder	Pellet	Film
Pros	Current STD	-Less mold flow -Low cost	-Direct exposed die -Low cost	Thin layer
Cons	PLP	Dust	-Dust -Mold flow	Less thickness flexibility

Compression mold system requires special powder which particle size is contolled well, because fine powder causes too much dust and blocking issue in the system and large particle powder causes delayed melt and abnormal appearance sometimes. As shown in (Figure 2), granule shape powder has narrow particle size distribution, and it is widely used for comression mold system.

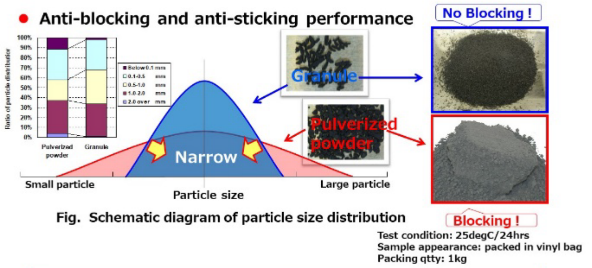
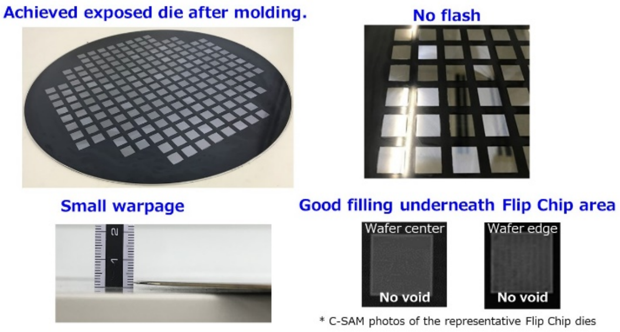


Fig. Schematic diagram of particle size distribution

Test condition: 25degC/24hrs
Sample appearance: packed in vinyl bag
Packing qtty: 1kg

Pellet form EMC has been standard for transfer molding. Transfer mold type WLP is still rare, but it is remarked because it is able to create exposed die structure directly without grinding process. (Figure 3) However, 12 inch wafer is very large compare to conventional transfer mold strip, and very low viscosity and long flow EMC is necessary. Generally, such low viscosity EMC cause resin bleed on exposed die surface, but it is able to control by filler distribution's optimization



* C-SAM photos of the representative Flip Chip dies

Figure 3. Direct exposed die WLP by transfer molding.

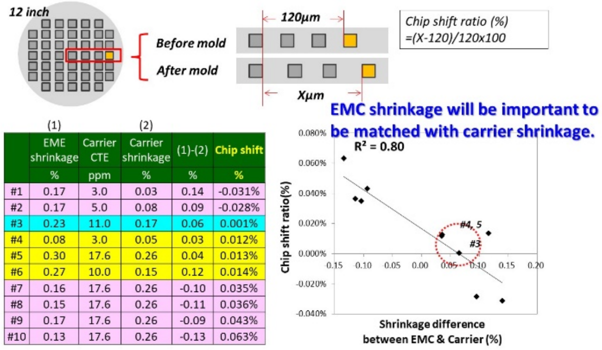
Vacuum lamination with film type EMC is suitable to create thin and wide mold layer like PLP, but it is not good at creating thick mold layer.

Comprehensively, compression mold with granule EMC should be the best balance mold system and material form in terms of costly, workability, and reliability.

RESULT AND DISCUSSION

Chip shift

CTE mismatching between EMC and carrier sometimes causes chip shift issue. Various carrier such as glass and SUS are applied for WLP. As shown Figure 4, it is important to minimize CTE mismatching between carrier and EMC.



	(1) EME shrinkage	Carrier CTE	(2) Carrier shrinkage	(1)-(2)	Chip shift
	%	ppm	%	%	%
#1	0.17	3.0	0.03	0.14	-0.031%
#2	0.17	5.0	0.08	0.09	-0.028%
#3	0.23	11.0	0.17	0.06	0.001%
#4	0.08	3.0	0.05	0.03	0.012%
#5	0.30	17.6	0.26	0.04	0.013%
#6	0.27	10.0	0.15	0.12	0.014%
#7	0.16	17.6	0.26	-0.10	0.035%
#8	0.15	17.6	0.26	-0.11	0.036%
#9	0.17	17.6	0.26	-0.09	0.043%
#10	0.13	17.6	0.26	-0.13	0.063%

Figure 4. Chip shift by CTE mismatching.

Warpage control

The most important property of EMC in customer process is warpage, because if warpage is large over 2mm customer does not treat wafer or panel in their several machine. Wafer warpage was greatly reduced from 30mm to less than 1mm (Figure 5a and 5b) across a wafer by tailoring the stress index which is defined as CTE1 times Flexural Modulus at room temperature (Figure 6). Figure 6 shows the correlation between each of the property and warpage. It was found that stress index showed the highest correlation with warpage in comparison with other properties.

In order to reduce the warpage, the CTE and flexural modulus of EMC must be reduced. In general, low CTE is achieved by the method of high filler content and low flexural modulus is obtained by adding some low stress additives (LSA) in the EMC (Figure 7).

Figure 5. Wafer with large (a) and low (b) warpage.

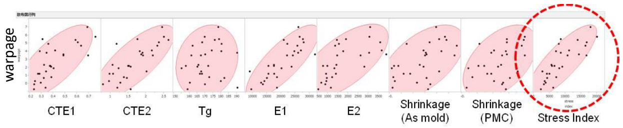


Figure 6. Scatter plot for various properties.

Table 1 shows the stress index comparison of EMCs with various filler content and LSA. As comparison between EMC-1 and EMC3, increasing FC is effective to make CTE1 smaller, however flexural modulus (E1) increase at the same time. Thus, stress index has no significant improvement. Meanwhile, LSA can make E1 smaller with keeping smaller CTE1 as comparison between EMC-1 and EMC-4, and EMC-4 shows the smallest warpage with 12 inch wafer (Figure 8). Therefore, LSA is key technology to control warpage.

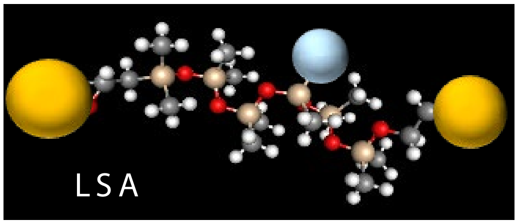


Figure 7. Low Stress Additive (LSA).

Table 2. Properties comparison of various EMCs.

Leg.	filler content [wt%]	LSA	CTE1 [ppm]	E1 [GPa]	Stress Index (CTE1 xE1)
EMC-1	90	null	7	26	182
EMC-2	89	null	8	23	184
EMC-3	88	null	9	21	189
EMC-4	90	yes	7	15	105

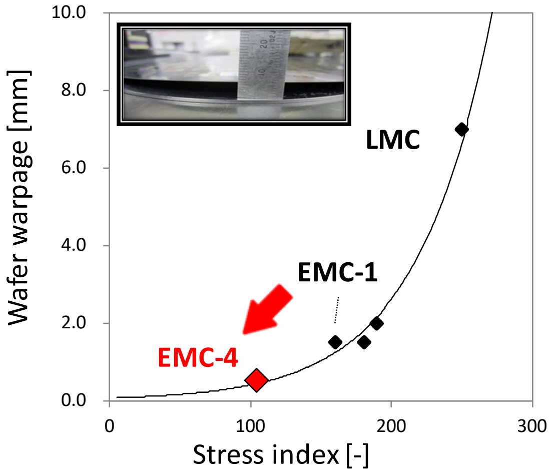


Figure 8. Warpage comparison of various EMCs

In addition, the molding parameter also influence the warpage performance. Warpage is induced by EMC curing shrink during the molding and thermal shrink from molding temperature to room temperature. Hence, EMC dimension change by lower molding temperature become smaller than 175 deg.C. as standard molding temperature (Figure 9).

Table 3 shows the 12 inch wafer warpage result with various molding temperature, the warpage by 130deg.C. molding is much smaller than it by 175deg.C molding.

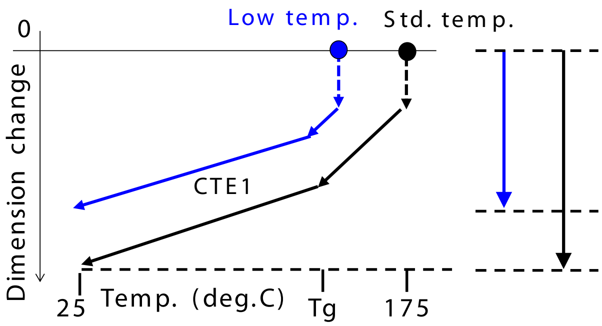


Figure 9. EMC dimension change during the molding.

On the other hand, the cure-ability is the one of concern for lower temperature molding. EMC formulates the curing catalyst for the cross-linking reaction between epoxy resin and phenolic hardener. The catalyst activity is determined by the thermal energy, so the catalyst activity become weaker in case of lower temperature molding. Thus, the relative longer cure time is necessary (Table 3).

To overcome this issue, we are developing new catalyst system, which can achieve 120-180 sec molding on 100-120 deg.C. (Figure 10).

Table 3. Molding temperature influence for warpage

EMC grade	Molding temp. [deg.C.]	Cure time [sec]	12 inch wafer warpage [mm]
EME-G730	175	120	1.0
EME-G730	150	300	0.8
EME-G730	130	600	0.6

*Carrier thickness : 760um, Mold thickness : 100um

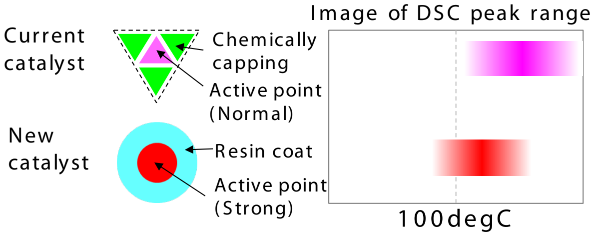


Figure 10. Concept of lower temperature cure-able catalyst

Re-distribution layer (RDL) material is also important material to control warpage of package for FOWLP. If number of RDL layer increase and volume of EMC in package decrease such as exposed structure (e.g., "Figure 11"), we need to control warpage by both EMC property and RDL material property. Figure 12 shows relationship of warpage and number of RDL.

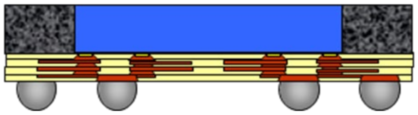


Figure 11. Exposed package with 4 layer RDL

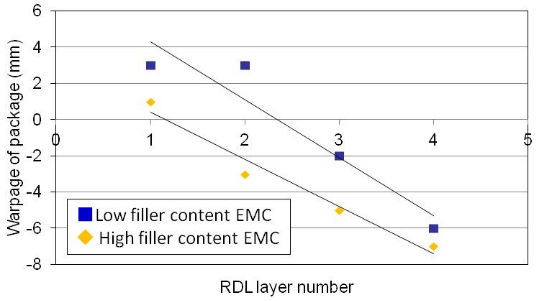


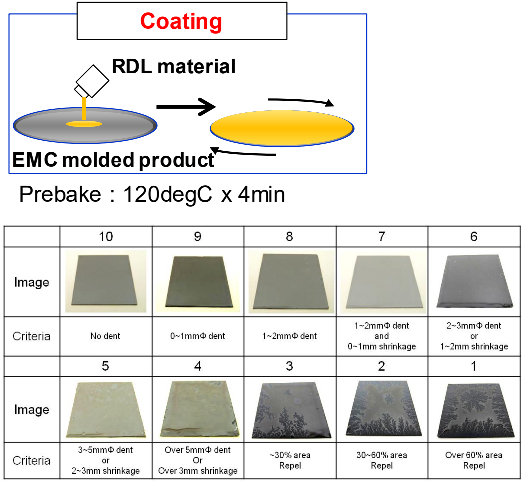
Figure 12. Warpage of exposed package

From these results, it is impossible to control warpage of multilayer by only EMC property. Now low stress RDL material is under development to minimize warpage of multilayer FO-WLP.

Compatibility with RDL material

In chip first process of Fan-out WLP/PLP, the RDL material is applied on the cured EMC surface. The major RDL is poly-imide (PI) or poly-benzoxazole (PBO) based material. On the other hand, EMC is epoxy based material. So EMC compatibility with RDL material is important.

We tested the additive type of EMC and RDL type affect to this compatibility (Figure 13). Even small amount of additive is formulated to EMC, it affects to repel performance (Figure 14).



Prebake : 120degC x 4min

	10	9	8	7	6
Image					
Criteria	No dent	0~1mmΦ dent	1~2mmΦ dent	1~2mmΦ dent and 0~1mm shrinkage	2~3mmΦ dent or 1~2mm shrinkage
	5	4	3	2	1
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Criteria	3~5mmΦ dent or 2~3mm shrinkage	Over 5mmΦ dent Or Over 3mm shrinkage	~30% area Repel	30~60% area Repel	Over 60% area Repel

Figure 13. RDL coating test method

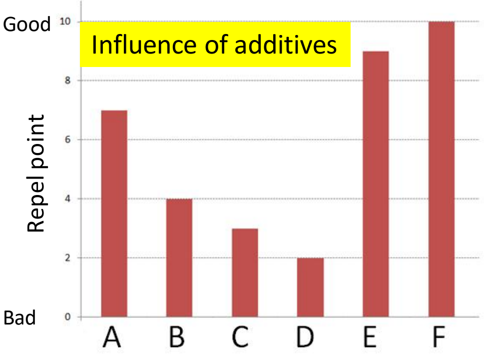
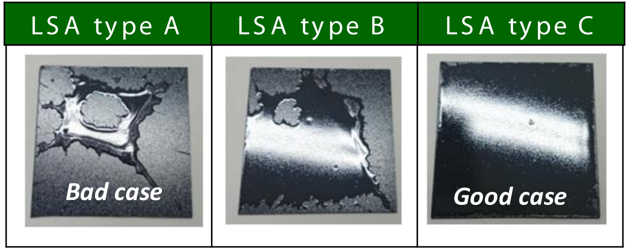


Figure 14. RDL coating test with various additives

Additionally, we found the LSA type (chemical structure) in EMC have large influence for the compatibility between EMC and RDL (Table 4). For example, EMC with LSA type A repel the RDL material. By contrast, EMC with LSA type C has higher affinity with RDL material. This is caused by LSA solubility difference to epoxy matrix. In other words, LSA type A has lower polarity, then it orientate EMC surface easily. On the other hand, LSA type C has higher polarity and solve to epoxy matrix inside mainly. Hence, these EMCs show the different compatibility with RDL (Figure 15).

Table 4. EMC-RDL compatibility



LSA type A	LSA type B	LSA type C
Bad case		Good case

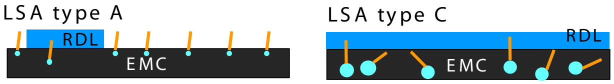
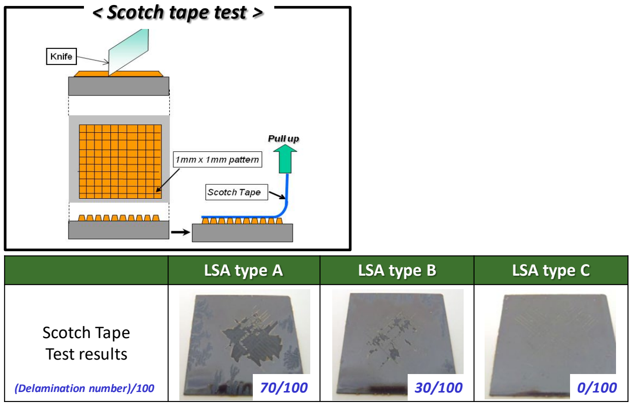


Figure 15. LSA distribution on EMC-RDL interface

In RDL 1st process, EMC is molded on cured RDL. So the adhesion between EMC and RDL has important. Figure 16 shows the adhesion strength by scotch tape test. As same as RDL coating test, LSA type affect to the adhesion strength, and type C shows the best performance.

Of course, the RDL type also contribute the compatibility with EMC, but these results suggest that the additive and LSA optimization is very important for FO-WLP/PLP EMCs

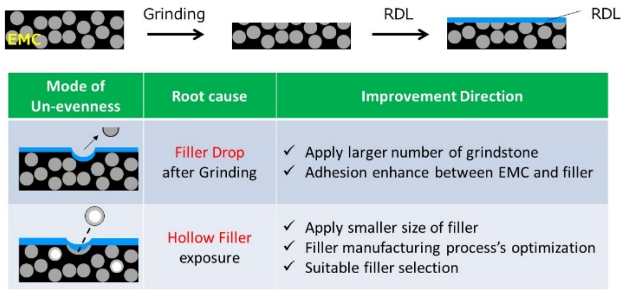


	LSA type A	LSA type B	LSA type C
Scotch Tape Test results (Delamination number)/100	70/100	30/100	0/100

Figure 16. adhesion test between EMC-RDL interface

Fine filler for FO-WLP

Some of FO-WLP process includes grinding process. By grinding, non-flat mold surface by filler drop and hollow filler sometimes prevent flat RDL layer creation. At the worst case, air is trapped in between RDL and hollow part, and then the air expands during RDL cure process, and causes function fail by Cu circuit break. Grinding process optimization and filler manufacturing process optimization improve this problem, but it is very difficult to remove completely. Best solution for this problem should be to reduce filler size. Currently, popular filler maximum size for FO-WLP is 10-20um, and <10um is challenging for advanced FO-WLP with fine L/S and narrow gap. (Figure 17)

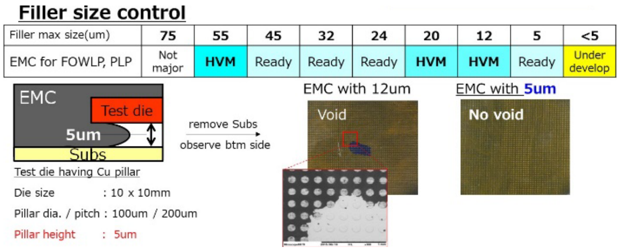


Mode of Un-evenness	Root cause	Improvement Direction
	Filler Drop after Grinding	✓ Apply larger number of grindstone ✓ Adhesion enhance between EMC and filler
	Hollow Filler exposure	✓ Apply smaller size of filler ✓ Filler manufacturing process's optimization ✓ Suitable filler selection

Figure 17. Filler drop and hollow filler issue.

In addition, fine filler is important for MUF of RDL 1st FO-WLP like Chip on wafer(CoW) . CoW uses micro bump, which has 15~35um gap, so very fine sieving filler like 5um is necessary. (Figure 18)

Thus, fine filler EMC must be necessary for advanced FO-WLP.


Filler size control

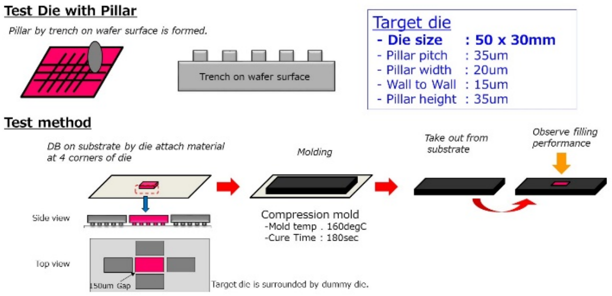
Filler max size(um)	75	55	45	32	24	20	12	5	<5
EMC for FOWLP, PLP	Not major	HVM	Ready	Ready	Ready	HVM	HVM	Ready	Under develop

Test die having Cu pillar
Die size : 10 x 10mm
Pillar dia. / pitch : 100um / 200um
Pillar height : 5um

Figure 18. Filling ability for narrow gap.

5um MUF micro bump filling challenges

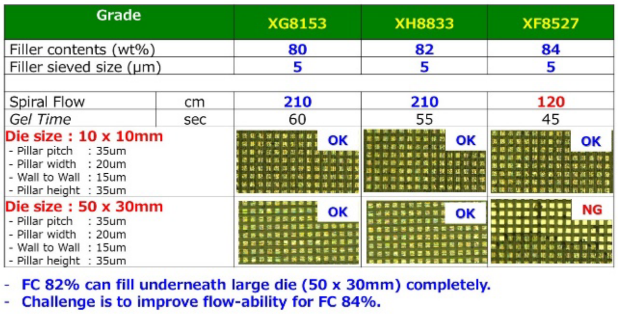
Test method for micro bump filling is shown in figure 19. Pillar by trench on 12 inch wafer was created. After singulation to 50x30mm or 10x10mm, the trench chip was attached on substrate, and then 15x35um gap like micro bump was created. 4 dummy die was placed around trench die to duplicate 2.5D device. After molding with 5um sieving EMC, mold part was peeled off, and then trench surface was observed by micro scope



Target die
- Die size : 50 x 30mm
- Pillar pitch : 35um
- Pillar width : 20um
- Wall to Wall : 15um
- Pillar height : 35um

Figure 19. Test method of very narrow gap filling.

As shown in figure 20, 3 EMC (XG8153, XH8833, and XF8527) with 5um sieving filler are evaluated. As we concerned, high filler loading with 5 um sieving filler actually caused short spiral flow (XF8527), and showed poor filling performance on 50x30mm die.



Grade		XG8153	XH8833	XF8527
Filler contents (wt%)		80	82	84
Filler sieved size (μm)		5	5	5
Spiral Flow	cm	210	210	120
Gel Time	sec	60	55	45
Die size : 10 x 10mm - Pillar pitch : 35um - Pillar width : 20um - Wall to Wall : 15um - Pillar height : 35um		OK	OK	OK
Die size : 50 x 30mm - Pillar pitch : 35um - Pillar width : 20um - Wall to Wall : 15um - Pillar height : 35um		OK	OK	NG

- FC 82% can fill underneath large die (50 x 30mm) completely.
- Challenge is to improve flow-ability for FC 84%.

Figure 20. Filling performance for narrow gap.

Melt-ability for good filing performance

In case of compression mold with granule EMC, spiral flow is not suitable indicator because of less mold flow. Melt-ability is much more important. If granule EMC smoothly melt on heated mold chase, it shows good filling performance for narrow gap. (Figure 21)

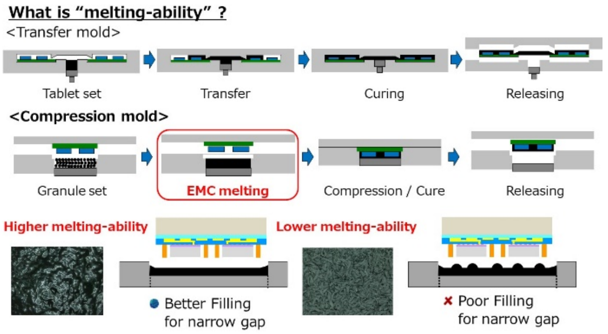


Figure 21. Melt-ability of granule EMC.

Melt-ability is quantified by binarization processing as shown in Figure 22. Al cup including granule EMC is placed on hot plate at 175deg.C/3min without any pressure. Some part melt and cure, and melt part looks white by the binarization processing. If white area per whole area is large, it indicates good melt-ability.

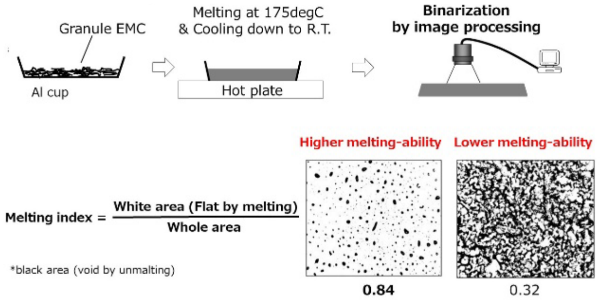


Figure 22. Quantification of melt-ability.

Melt-ability is influenced by various factors. Especially, filler content and filler SSA have big impact for melt-ability, for example, high filler loading and fine filler induce EMC's poor melt. It is undesirable tendency for warpage and narrow gap filling. Very fine filler create agglomeration, and it is one of root cause of poor melting. Silica filler's surface has a lot of Si-OH, which is modify-able by various chemicals. Recently, we figure out that some long chain monomer modification prevent filler agglomeration and improve melt-ability (Figure 23).
We expect the filler surface modification technology brings break through solution. Further improvement and optimization is continued.

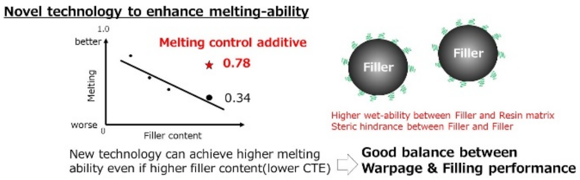


Figure 23. Quantification of melt-ability.

Conclusion

FO-WLP process includes a lot of new process and challenging targets compare to standard back-end process. Compression mold with granule EMC provides better workability and reliability, and it is the best systems comprehensively. As for advanced FO-WLP include fine L/S and narrow gap filling, continuous EMC improvement must be necessary.

Acknowledgment

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