Challenges of Large Format Packaging and Some of Its Assembly Solutions

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Abstract

This paper will focus on the technical challenges and solutions that a packaging and/or equipment engineer faces during the encapsulation of a large format substrate - either a wafer or panel substrate. This form of packaging is known as Large Format Packaging (LFP). The technical challenges and solutions discussed here include encapsulant, material dispensing strategies, direction of encapsulation, warpage management and challenges for LFP going forward. LFP as a packaging solution is an option worth exploring when the end user is willing to address its set of engineering challenges appropriately.

Key words

Compression encapsulation, encapsulant, large format packaging (LFP), liquid dispensing, ORCAS, warpage

I. Introduction

The wafer and panel packaging are now the most talked about in trade publications and professional reports. It could be a sizeable market in the future. The recent happenings in the industry provided us a glimpse of what the large format packaging could offer for advance packaging in terms of its potential in improving functionalities and multi-applications. One such case is the mobile phone maker that uses the Fan-Out technology for their application processor while the other case is the acquisition by a major OSAT over another OSAT that specialized in wafer level packaging. These gave us a heads-up of what the current packaging and assembly methodologies that made use of leadframe to produce packages will have to share their workspace with such large format substrate. The advent of producing these packages on either the wafer or panel level format will eventually arrive although it is still at its stage of infancy. In our recent packaging and assembly work, we found that producing microelectronics package using wafer or panel level format is feasible from the perspective of production cost and technology. From the perspective of cost production, a chunk of the manufacturing process can be eliminated, for instance, interconnected technologies using wire bonding. If LFP method of production is adopted, it could be translated as a reduction in production cost and an increase in throughput. We found that using ∅ 8” diameter wafer to produce a 5S or 6S packages of less that 1mm dimension all around, we can encapsulate about two hundred and thirty thousand unit per wafer. Assuming a 30 hour work week, 20 working days in a month and 11 working months in one year, a single encapsulation system can produce almost three billions units. The focus of our paper is to share our LFP encapsulation experience in producing such a package.

We will discuss the challenges that a packaging/equipment engineer faces while producing packages using large format substrates. Engineering challenges and possible solutions will be deliberated with experimental data to substantiate whether it is performed either on a wafer and a panel substrate. We will end this paper with the discussion of challenges and future of LFP.

II. Encapsulant Materials and Dispensing

Materials that are available for encapsulating a wafer and panel are granular, liquid and molding sheet, see Fig. 1. Based on Yole 2017 report on “Equipment and Material for

Fan-out Packaging" , the mostly commonly used among the three forms of encapsulant is liquid.

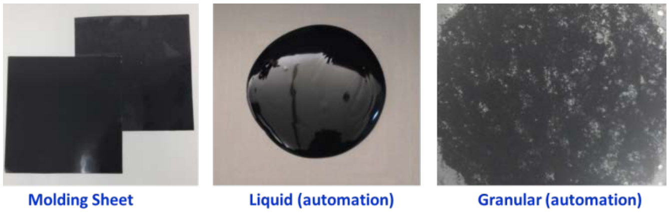
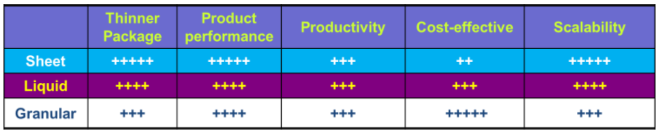

Molding Sheet Liquid (automation) Granular (automation)

Fig. 1: Different Types of Encapsulant

These materials in general will have to posses certain desirable mechanical, electrical, thermal and other miscellanous properties. In mechanical properties, we are interested in their tensile strength, internal thermal stress and elongation at breakage. Electrical properties of interest include volume resistivity (Ω-cm) dielectric constant and losses. Thermal properties of encapsulation to watch out for are curing temperature, glass transition temperature (Tg) and co-efficient of thermal expansion (CTE). As for miscellanous properties, end user tends to look at its water absorption and adhesion behavior. A study on the different forms of encapsulant was performed by some of the researchers of this paper.



	Thinner Package	Product performance	Productivity	Cost-effective	Scalability
Sheet	+++++	+++++	+++	++	+++++
Liquid	++++	++++	+++	+++	++++
Granular	+++	++++	+++	+++++	+++

Fig. 2: Rating of Encapsulant Performance

Fig. 2 shows the outcome from the perspective of compression molding [3] and our discussion in this paper will focus only on liquid. Among the three forms, the most commonly used is liquid and one of the key reasons is because liquid does not cause foreign material contamination unlike granular within the working area of the equipment. This is important as many a times the compression molding equipment is housed in the same vincity of other downstream processes such as UV operation, RDL etc thus, resulting in liquid as a choice consumed encapsulant. A study on different liquid dispensing (see Fig. 3) was carried out to analyse how it impacts moldability such as flow mark. Since our substrate is a panel (see Fig. 4) we will focus the discussion on glob and line (also known as rectangular) patterns. The direction of molding is performed with the die facing downward with a closed loop automatic co-planarity monitoring system, which observes the mold cap thickness variation during encapsulation and corrects it in real time to the design specification. Such control is in-built to the mechatronics press of the ORCAS machine that we used for our compression molding where the co-planarity monitoring will dynamically control the final mold cap thickness to within TTV (total thickness variation) of 20 µm.

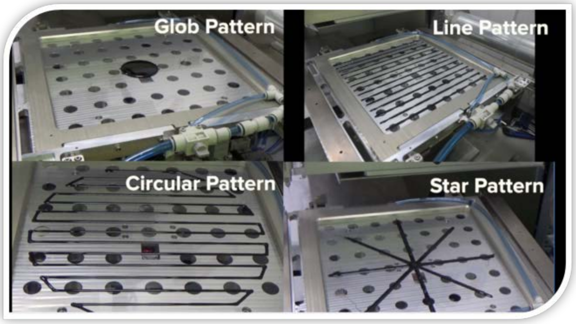


Fig. 3: Different Liquid Dispensing Patterns

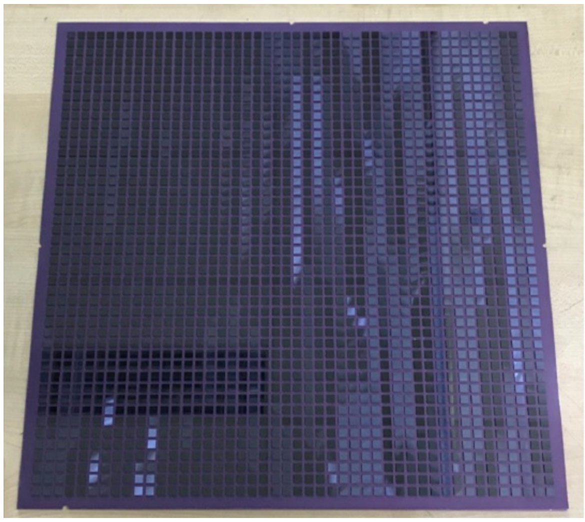


Fig. 4: Typical Panel Fan Out Layout SQ 300mm

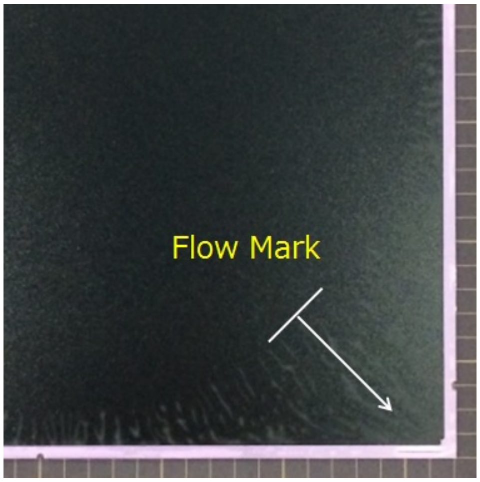


Fig. 5: Flow Mark Point of Measure

The point of measures on how we attempt to quantify this study of flow mark with different dispensing patterns are shown in Fig. 5.

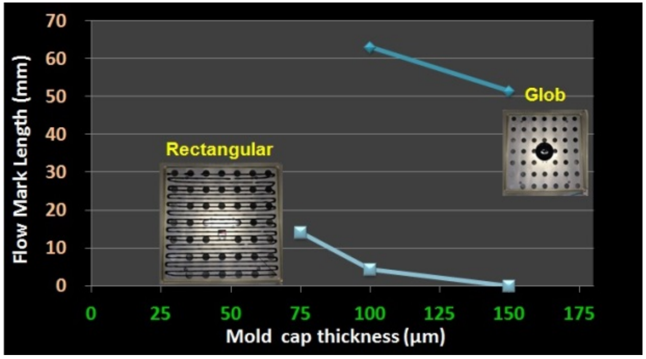


Fig. 6: Glob vs. Rectangular Dispensing Pattern

The design of experiment to study the performance of glob versus rectangular pattern is performed for different mold cap thickness. The result of this study shows (see Fig. 6) that rectangular dispensing is effective in reducing the flow mark as compared to glob for every different mold cap thickness encapsulated. The material use for this study is the same for both patterns with approximately 85% loading with a top cut filler of 25µm.

There are reasons for such outcome. Firstly, when using a rectangular patterns the coverage of the encapsulant on the package is larger. This resulted in the flow path of the liquid encapsulant to become shorter as compared to a glob which has to travel a longer distance from the center of the package up to the final mold cap outline. Secondly, it is found during our study by the researchers that due to [6] the result of filler separation, a condition filler aggolermation was subsequently created at certain spots [see Fig. 5]. Thirdly, the resin within the encapsulant with less viscosity will tend to flow faster towards the end of molding as compared to the filler being solid become sluggish as it flows.

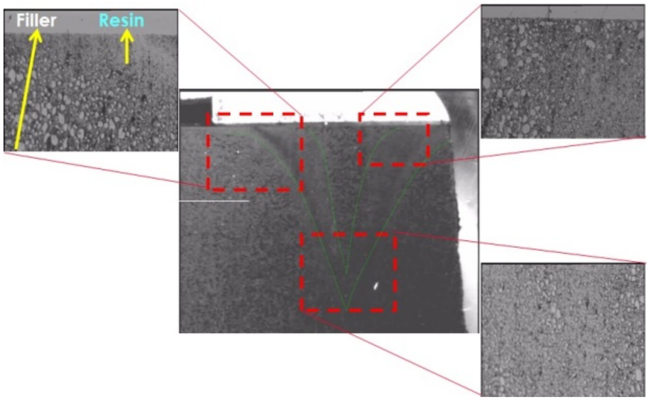


Fig. 7: Epoxy Resin and Filler Separation

Fig. 7 is microscopy to illustrate this epxoy resin and filler separation. From our study we found that the areas of flow mark had silica filler concentrated along those "streamline" as seen in Figure 7. This finding may imply that in future work on large format packaging with dispensing system for compression molding must be equipped with the capabilities to move at wider distance of travel dispense as oppose to a simple glob displacing. Even for spin coat, it can become a mechanical challenge if the substrate is not a circle but a quadilateral shaped.

As an observation point there should be a good opportunity for molding sheet when large format packaging made use of panel greater that square 340mm (SQ 340). The liquid dispensing pattern will be too stretched if the panel size is 700mm x 700mm. This is because the application of mold sheet is similar to the concept of slapping a piece of cheese to the turkey sandwich. The only engineering challenge that might occur is for instance; if the package is a fan out type or SiP and when there is a missing dies or components, how could one reduce the amount of encapsulant material based on Archimede principle of volume compensation during automation. However, if the encapsulant is a either liquid or granular and it is known prior to compression molding, it can be programmed at the dispenser to dispense the correct amount of encapsulant to compensate for the actual weight requirement as a result of such missing silicon dies and/or components.

III. Direction of Compression Encapsulation

The opportunity for the application of large format packaging is multi-facet. LFP is applied in future packaging for the reason of CCCV [5]. In this paper the authors discussed about high mobility and "On the Go" computing that requires a wide range of functions and low power consumption in particular to Internet of Things (IoT). This wave will leverage the many years of innovations the semiconductor industry have created and in particular integrating semiconductors into a very small form factor (miniaturization) to either system-on-chip (SoC) or system-in-package (SiP).

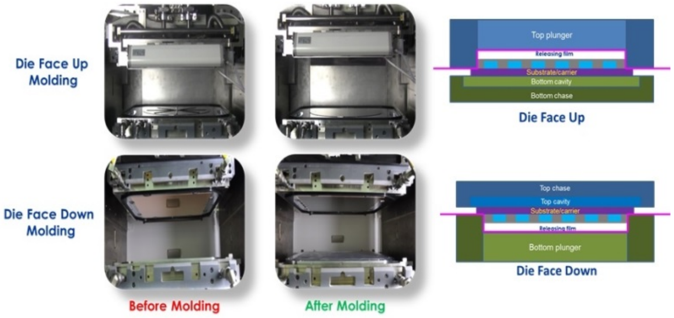
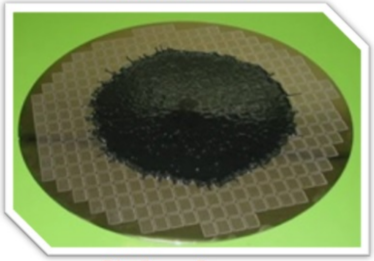


Fig. 8: Compression of Molding Direction

The large format packaging is a potential solution to become a practical reality which encompasses the requirement of performance, form factor, reliability and cost. As such which package is assembled by LFP would also somewhat dictate the compression molding direction. There are two directions to mold LFP, either die facing up or die facing down, as shown in Fig. 8. The molding direction to mold will have to depend on the type of package.

Generally fan out, expose bump and 5S/6S type of LFP are molded die face up because it does not have a complex structure as opposed to a LFP MUF type of structure. During face up molding, the encapsulant will dispense either on the wafer or panel. The air trapped during dispensing is present in particular direct glob dispense pattern shown in Fig. 9. This can result in air trapping with a possibility of formation of mold void. The solution is generally overcome by applying vacuum to remove such potential air trap within the molding tool. In fact, application of vacuum to remove air trap is found even in injection molding of high quality parts.

Die Face Up
Direct Dispensing



Die Face Down
Indirect Dispensing

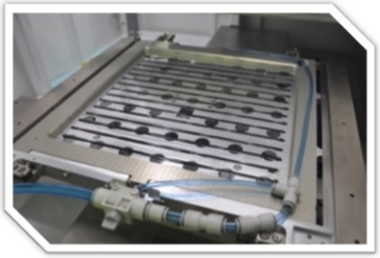


Fig. 9: Dispense for Die Face Up vs. Die Face Down Molding

When the molding direction is die face down, the epoxy molding encapsulant is dispensed outside onto a film and brought into the molding system. It is noted here that either direction of molding dispensing should never be performed within a heated molding tool as the thermoset plastic polymerization chemical reaction will shorten the molding processing window when it is heated as it is being dispensed on the substrate or the film. Die face down molding is applied when LFP is a MUF or SiP which have micro gap that needs to be filled with epoxy molding encapsulant molding.

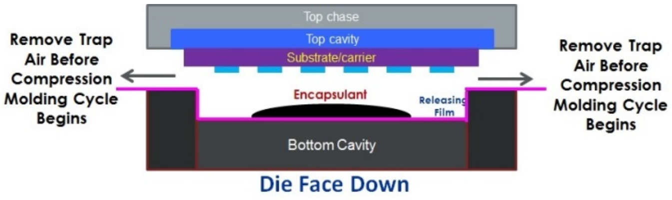


Fig. 10: Evacuation of Air Trap Before Compression Molding Cycle

The logic to first heat up the encapsulant is to obtain an optimal flowability which can be measured by the viscosity such that it can flow into this micro gap that could be as small as 30 µm. In addition to any air trapped within the package before it comes into contact with the encapsulant, (as shown in Fig. 10) it will be removed.

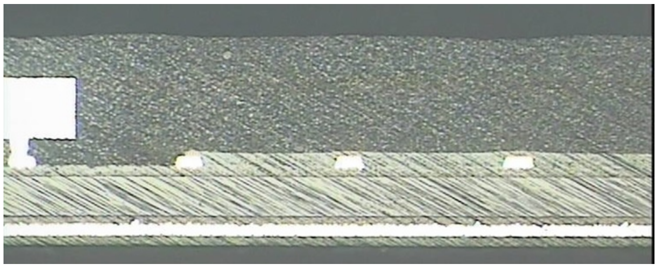


Fig. 11: Zero Voiding with Optimal Evacuation of Air Trap Before Compression Molding Cycle

To achieve this evacuation of trap air, the molding system is pre-programed to enable the vacuum process and allows contact between substrate and heat encapsulant before the closure for compression molding. It is generally a challenge but when optimally carried out, it can lead to zero voiding outcome, see Fig. 11.

IV. Warpage Challenge in Large Format Packaging

Warpage is defined as an out-plane bending and deformation [4]. There are many factors that influence warpage such as composition of encapsulant, molding temperature, package form factor/geometry, CTE mismatch among the encapsulant-substrate-silicon die and impact of back grinding , to name a few. Large format package tends to warp more severely as it involves the packaging of a large surface area which includes its thinness, CTE of the substrates; mold cap thickness and impact of silicon die [7]. In this section we will discuss some of the warpage findings using liquid encapsulant, with variable such as the amount of volume versus epoxy molding compound (mold cap thickness). The model of study is shown in Fig. 12 below.

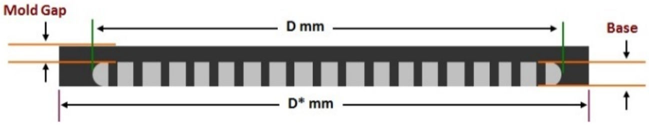
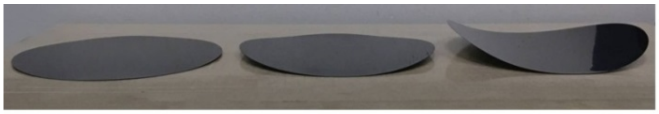


Fig. 12: Warpage Model Study to Assess Impact of EMC and Silicone Die Volume

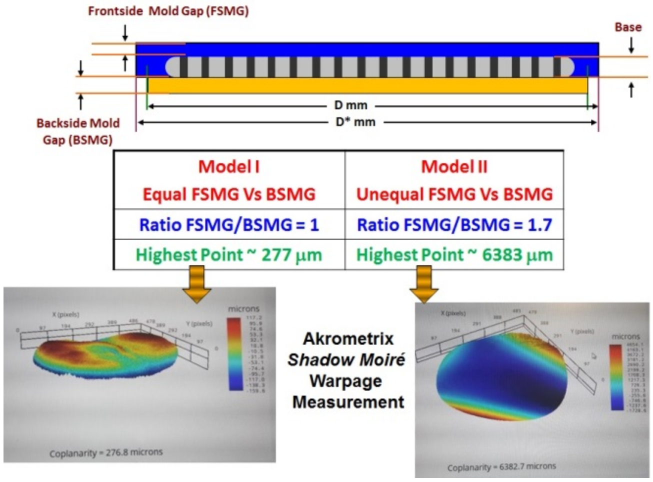
The objective of this experiment is to understand the impact of epoxy molding compound versus silicone volume, and to develop a model on how to minimize warpage for a variety of LFP during compression encapsulation. From this study we found out that if we have a good control in reducing the ratio of mold cap thickness (EMC volume) to the amount substrate volume (silicon volume), there is a chance that warpage can be minimized assuming that the encapsulant properties have been optimized. The result of this experiment shows that, when there is a good balance of epoxy and silicon volume, the warpage can be keep minimum, see Fig. 13.



Model A Base line	Model B	Model C
Ratio MG/Base = 1	Ratio MG/Base = 1.3	Ratio MG/Base = 2.1
Highest Point ~ 1mm	Highest Point ~ 4mm	Highest Point ~ 13mm

Fig. 13: Warpage Can Be Minimized By Optimization EMC and Silicone Die Volume

To further extend this conceptual finding, we apply the outcome to a 6S large format molding where the silicon volume is keep constant, while the mold cap thickness between the top (FSMG) and bottom (BSMG) mold cap are adjusted accordingly. The result of the experimental work is shown in Fig.14. We found that if the ratio of epoxy encapsulant of a 6S LFP is almost equal, the chance of having controllable warpage of < 1mm is possible. This lower level warpage is optimal for downstream process handling such as laser singulation which generally likes to have molded substrate to be as flat as possible, so that it can be easily hold down on the singulation stage.



Model I Equal FSMG Vs BSMG	Model II Unequal FSMG Vs BSMG
Ratio FSMG/BSMG = 1	Ratio FSMG/BSMG = 1.7
Highest Point ~ 277 μm	Highest Point ~ 6383 μm

Figure 14: Warpage Performance When Silicone Die Volume Is Keep Constant

Taking this idea further, we took one complete blank silicon wafer and one with trench created to conduct a molding trial. We found that the warpage level is lower for wafer without trench as compared to the silicon wafer with trenching, see Fig. 15 for this outcome. This is because the silicon wafer with trenching has a higher volume of epoxy molding compound, which means that ratio of EMC to silicone is >> 1.

Fig. 15: Warpage Comparison No Trench vs. Trench Silicone Wafer [3]

Besides controlling the encapsulant and silicon ratio amount, warpage after mold can be reduced during post mold curing (PMC). The purpose of performing PMC is to ensure that the chemical is fully cured where all the chemical bond and structure are fully formed and linked. PMC is known to be completely cured with a 100% chemically cross linked chemical structure. Fig. 16 is an illustration of encapsulant cure state after molding and PMC.

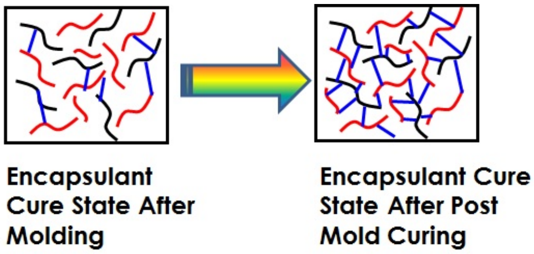


Fig. 16: Encapsulant after Mold and PMC [5]

In addition to using restrain during PMC and ratio of EMC/Silicone, we found that for the same LFP outline, the difference in substrate CTE for the same amount of encapsulant and silicone die can result in very different warpage performance.

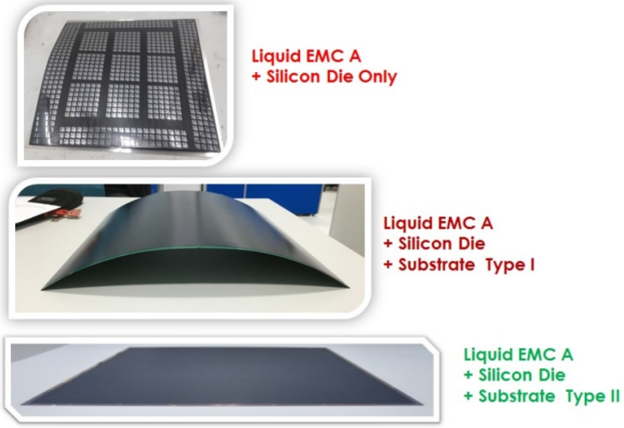


Fig. 17: Impact of Substrate CTE on Warpage

The top image of Fig. 17 is purely encapsulant/silicon, middle image is encapsulant/silicon/substrate Type I and bottom image is encapsulant/silicon/substrate Type II. The size of this panel is 340mm x 340 mm and they are all encapsulated with the same mold cap thickness and amount of silicon die but different CTE substrate type to demonstrate CTE matching on warpage reduction. The result of Fig. 17 shows how by matching CTE with encapsulant and silicon can influence the warpage LFP after post mold curing.

As an observation point, the warpage level after molding can be drastically reduced if there is proper balance of EMC volume, silicon die and CTE material among encapsulant-silicon-substrate. Fig.17 provides the physical evidence of these observations.

V. Challenges of Large Format Packaging Adoption Going Forward

There are many reasons for designers and manufacturers to embrace the trend of adopting large format substrate for packaging of plastic microelectronics. For instance, value-adding factors such as packaging flexibility, extreme form factor reduction, and cost. The flexibility of LFP as packaging format for encapsulation can be compared to convection oven where the equipment can be used to churn out any dishes ranging from baked poultry to pastries, so long as it can be fitted onto the oven baking tray. In molding terms, it can be either a wafer or panel outline and you can package anything you can imagine, ranging from discrete package, MUF, SiP and even PMIC (power management IC) with the molding tool. Like anything else, there bound to be challenges for this adoption. Many of these are discussed in trade journals such as Solid State Technology as well as well researched professional reports sold by Yole and Techsearch, to name a few.

For end user to switch to this form of assembly and packaging there will always be the question of return of investment if they will to proceed with the implementation and what will it be like. For instance the OSAT would need to understand if the fabless customers are willing to switch to this format and trust that this new method of assembly and packaging will provide them with the same or even better performance, yield and etc. At the same time, helps to reduce their packaging costs as compared to the existing production methods. Next, what standard substrate format size is to be used and for panel, what size to use, since there have not been any established industry standard. Also, will there be processing equipment that is sufficiently flexible during manufacturing, when the end user switches from wafer to panel substrate and vice versa. Will there be any equipment manufacturer for various processes willing to come on board to invest, design and deep dive to produce equipment for the LFP manufacturing? Lastly, what are the engineering challenges out there that are still outstanding and waiting for solutions to be developed? Take for example; can we have line/space below the current 10μm/10μm for panel? There are many other considerations for LFP to become a mainstream manufacturing before it can take off. However, it benefits reaped in the long run are likely to out weight the current challenges. A look a Figure 18 will provide an inside on the productivity benefits of large format packaging in particular panel format if all the engineering challenges can be resolved and will lead to substantial low package cost in totality.

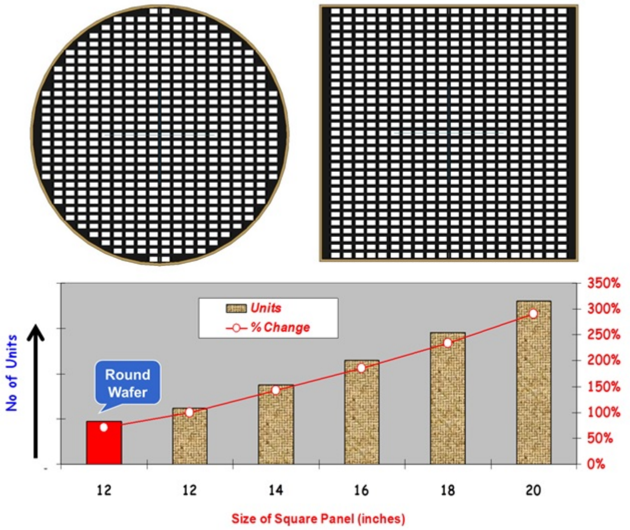


Fig. 18: Potential Productivity Benefits of LFP

VI. Conclusion

The challenges of large format packaging and some of its assembly solutions have been investigated in this study. Some important results and recommendations are summarized in the following.

- Based on this work, we found that large format package is a cost effective packaging solution to produce packages going forward.
- Flow mark is a result of filler separation from resin and clustering of filler. The solution to obtain good flow mark is a combination of flexible dispensing patterns and good material system.
- For large format packaging, the dispensing system for compression molding must be equipped with capabilities to move at a wider distance of travel dispense.
- The direction of compression molding is critical for packages that are MUF/SiP in nature due the potential of voiding.
- To have good warpage control, our study shows that we need to consider the encapsulant-silicon proportion balance together with a matching substrate CTE.
- The challenges for adoption of LFP are: (a) attractiveness of return of investment to both end user and equipment supplier, (b) readiness of solutions for outstanding engineering challenges, and (c) the possibility of standardization for substrate size in particular panel type of substrate.

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