# Investigation on Die Shift Issues in the 12-in Wafer-Level Compression Molding Process

Lin Bu, Siowling Ho, Sorono Dexter Velez, Taichong Chai, and Xiaowu Zhang, *Senior Member, IEEE*

***Abstract*— Die shift issues that arise in embedded wafer-level packaging because of the mold flow process is investigated in this paper, along with solution strategies to address them. The nonlinearity trend of the die shift in the experimental inspection is explained and captured by the numerical simulation with a consideration of the coefficient of thermal expansion effect coupled with the mold flow effect. Optimizing the initial diameter of molding compounds, increasing the thickness of molding compounds, and reducing the filling speed are the three solutions we demonstrate for reducing the drag force. Die shift generated by the mold flow could be reduced by optimizing these controllable parameters.**

***Index Terms*— Coefficient of thermal expansion (CTE), die shift, embedded water-level packaging (eWLP), mold flow effect, nonlinear.**

## I. Introduction

RECENTLY, embedded wafer-level packaging (eWLP) is evolving rapidly in the semiconductor industry, especially for usage in portable devices such as small modules for mobile phone applications. Because of its high density integration, low profile package, and high yield, eWLP will play a bigger role in future 3-D integrated circuit [1]. One of the biggest processing issues in eWLP technology is die shift in 12-in wafer-level molding process. In the die shift problem, the die is not swept completely away from their original position. Instead, a slight shift in position is observed. This slight shift in die location creates problems for subsequent wafer processes, such as the formation of redistribution lines. A major contributing factor of die shift is the thermal expansion of polymeric molding tape, because of its high coefficient of thermal expansion (CTE) value ($> 35$ ppm/K) in combination with the high molding temperature.

Significant results were achieved in previous researches, focusing on die shift issues arising from the CTE effect. Gaurav *et al*. [2] constructed a finite-volume model to investigate various strategies in obtaining low die shift values. They found that low CTE and low cure shrinkage mold compound materials are mandatory to achieve low die shift values during wafer molding. Aditya *et al*. [3] carried out process optimization to reduce the die shift, resulting in a significant reduction ($\sim 80\%$) in die shift. Die shift was further characterized in terms of molding compounds and carrier types, which contribute to CTE effect, by Kim *et al*. [4]. The behavior of die shift was significantly affected by the material properties of molding compounds as well as that of carriers. Their findings revealed that material properties of both the molding compound and the carrier should be considered carefully to minimize the magnitude of die shift. Khong *et al.* [5] established a 2-D transient model to investigate the wafer-level molding process. They found that the local shear rate is increasing linearly from the center of the wafer to the outermost die. The die shift is inversely proportional to the die thickness for wafer-level molding. Mazuir *et al.* [6] studied the effect of the adhesion between thin silicon dies and the adhesive carrier through die shear measurements. Through optimizing the pick and place parameters, it is possible to reduce the die shift from 600 to 30 $\mu$m. This improvement leads to considerable reduction in the risk to failure in the photolithography, the wafer-to-wafer alignment and the through mold via steps. Gaurav *et al.* [7] carried out the parametric studies on thermal release temperatures and molding temperatures. The thermal release temperatures range from 393.15 to 573.15 K. The highest thermal release temperature molding tape has highest associated adhesive strength. Using the highest adhesive strength tape leads to a reduction in die shift during the wafer molding process. Reducing the molding temperature also leads to reduction in die shift during wafer molding. Molding temperatures ranging from 398.15 to 448.15 K are evaluated. A molding temperature of 423.15 K is found to reduce die shift and also leads to excellent mold ability.

In the experimental inspection, die shift is found to be nonlinear at the die or the two dies at the peripheral. Die shift because of the CTE effect, however, exhibits a linear trend in the numerical simulation. Hence, other factors must have an effect on the die shift formulation. In this paper, the flow effect is investigated and the nonlinear trend is captured in the numerical simulation. A conclusion could be drawn that the die shift phenomenon is a joint effort of CTE effect and mold flow effect. Three strategies are proposed to reduce the die shift because of the flow effect.

## II. Package Description

Institute of Microelectronics at the Agency for Science, Technology, and Research (A*STAR), Singapore and its industry partners developed an embedded device technology, based

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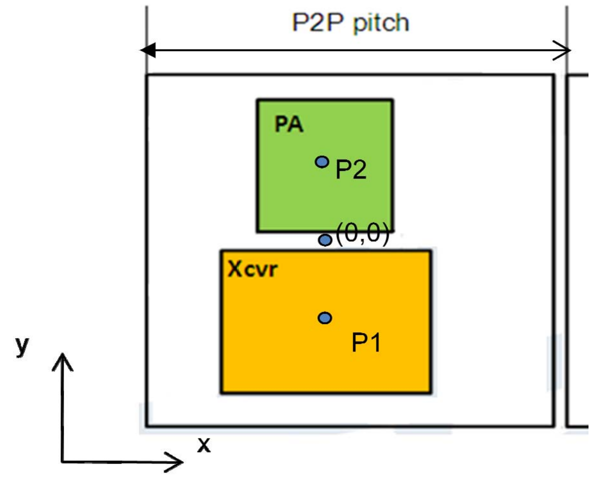



Fig. 1. Schematic plot of package design.

TABLE I
PACKAGE DETAILS

| Component | Package design |
|---|---|
| Transceiver (Xcvr) | 9.0x6.0x0.3mm |
| | P1 (0, -1.65mm) |
| Power Amplifier (PA) | 5.0x3.0x0.3mm |
| | P2 (0, 3.15mm) |

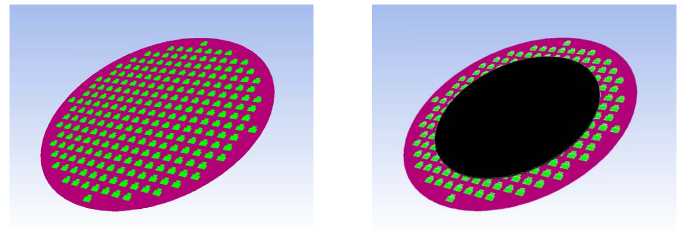
on a molded 12-in reconfigured wafer. A schematic plot of package design is shown in Fig. 1. The package size is 15 × 15 mm with a package thickness of 550 $\mu$m, and the size of the two dies are 9 × 6 mm [designated as transceiver (Xcvr)] and 5 × 3 mm [designated as power amplifier (PA)], with both 300-$\mu$m thick. The specifications of packages are listed in Table I. The gap between the big die and small die is 30 $\mu$m.

## III. Modeling

To further understand the die shift issues because of the mold flow effect in the molding process, computational fluid dynamics (CFD) simulation is a valuable tool. Establishing a validated model is, however, a challenging task. In this paper, a 3-D finite-volume model is established, as shown in Fig. 2. Molding compound flows past the chips during the molding process. The melting front is tracked by volume of fluid method, which was proposed by Hirt and Nichols [8]. There are four reconstructed methods in FLUENT software, which are modified HRIC, QUICK, CI CSAM, and compressive and geo-reconstruct. Geo-reconstruct methodology is regarded as the most accurate method in simulating the two-phase flows. Therefore, geo-reconstruct methodology is adopted in this paper. The compression motion of the top mold chase is controlled using dynamic mesh technique of FLUENT.

The modeling consists of the following assumptions.

1) A 3-D time-dependent analysis will be performed on a numerical model of the reconfigure wafer with fully populated two-die packages.



(a) (b)

Fig. 2. CFD model of the reconfigured wafer with fully populated two-die packages. (a) Without molding compound. (b) With molding compound.

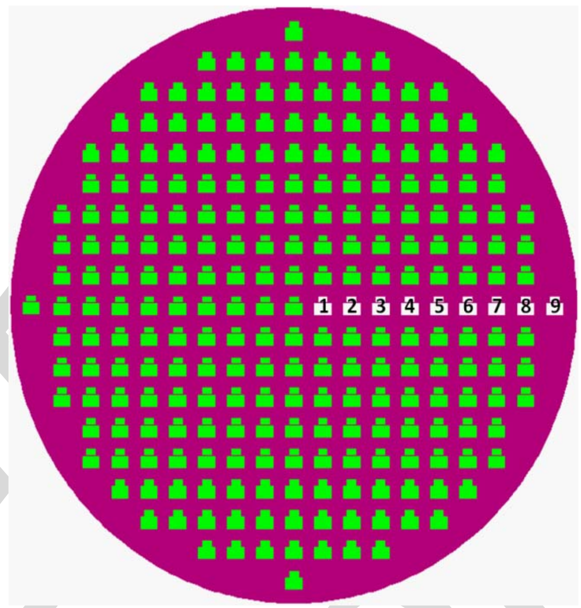



Fig. 3. Monitoring chips.

2) The mold compound is modeled with a shear-rate-dependent viscosity obeying the cross model.

3) Molding compound is assumed to be fully melted at the initial time.

## IV. Validation

To benchmark the modeling methodology developed in this paper, the numerical results are compared with the experimental results. From the previous studies [9], the compression mold flow exhibits an axi-symmetric pattern throughout the entire filling stage, such that the dies at the same radial locations experience the similar drag force. Therefore, a series of dies having the different radial positions was investigated in the previous research, as shown in Fig. 3.

The benchmarking solution can be categorized into three steps. Initially, using the commercial software FLUENT to perform the mold flow simulation, then the output of the mold flow results are put into ABAQUS to conduct the mechanical simulation. In consideration of the die shift effect attributed by mold flow, a finite-element model consisting of the dies, mold tape, and mold plate is built. The pressure distribution on the walls of the dies is extracted from FLUENT and pressure distribution map is subsequently applied on the surfaces of the dies in ABAQUS. The die shift attributed by CTE and

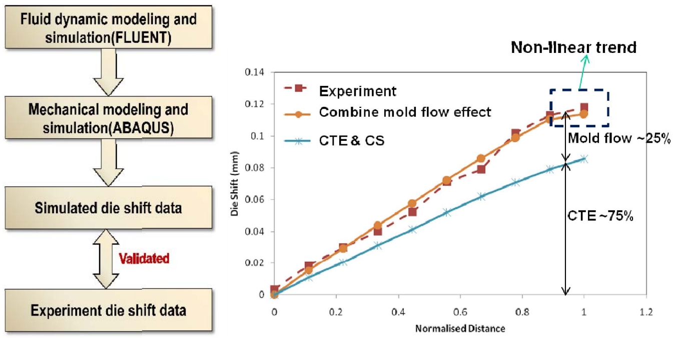



Fig. 4. Comparison of the experimental and numerical results.

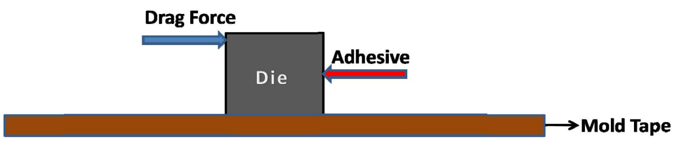



Fig. 5. Schematic plot of forces acting on the dies.

chemical shrinkage is obtained from a separate finite-element model. The simulated die shift data are obtained in this step from the outputs of ABAQUS. The comparison of the experimental and the simulation results is shown in Fig. 4. The nonlinear trend is well captured by the simulation. It can be found that the simulated results match well with the experimental results. Though the effect of mold flow could not be neglected, CTE effect is still the dominating effect in die shift. Around 25% of die shift is contributed by the mold flow effect and 75% by the CTE effect.

## V. Results

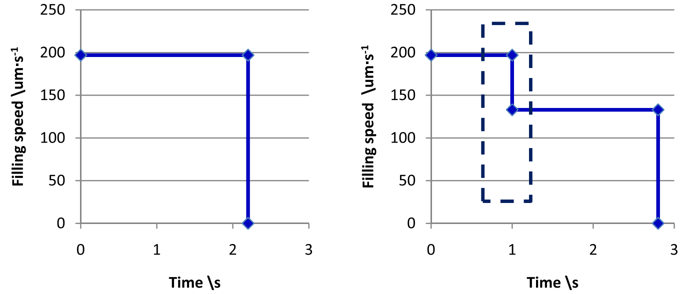
The forces acting on the dies, i.e., drag force versus adhesive force, are shown in Fig. 5. Once the drag force exceeds adhesive force, die starts to slide away from their original position [9]. A flow drag force is, however, below adhesive force in this paper and a slight shift in position is occurred. To further investigate the die shift because of the mold flow effect, the darg force exerted on the dies must be studied.

Filling speed of the top mold chase, initial thickness, and diameter of molding compound are several controllable parameters, which could easily be changed in the molding process without additional cost. In this paper, the variations of these parameters are investigated to see their affects on the drag force.

### *A. Reducing the Filling Speed of the Top Chase*

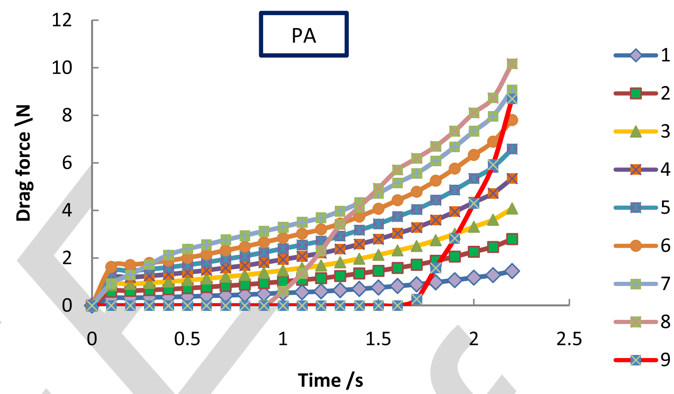
Two kinds of velocity profiles are investigated in this paper, as shown in Fig. 6(a) and (b). In the single-speed method, the filling speed is 197 $\mu$m/s. The thickness of the molding compound is 0.98 mm and the initial diameter of the molding compound is 210 mm. This case is set as a standard case in this paper.

In the multispeed method, the filling speed is initially at 197 $\mu$m/s and subsequently reduces to 133 $\mu$m/s at 1 s. For the chips investigated in this paper, the drag force in the

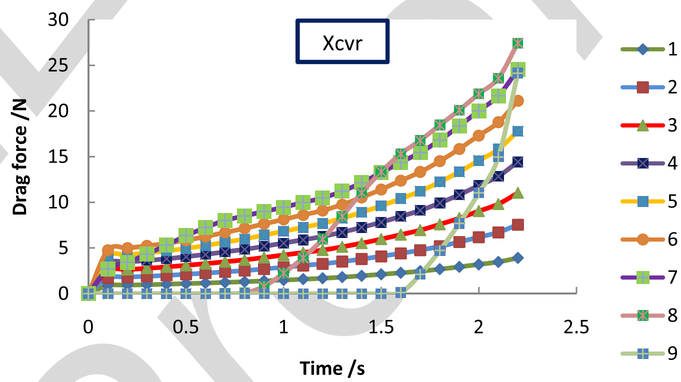



(a) (b)

Fig. 6. Velocity profiles of the filling speed. (a) Single speed (standard case). (b) Multispeed.




(a)

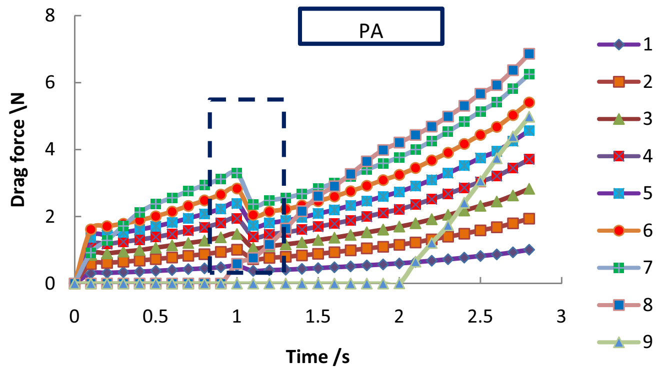



(b)

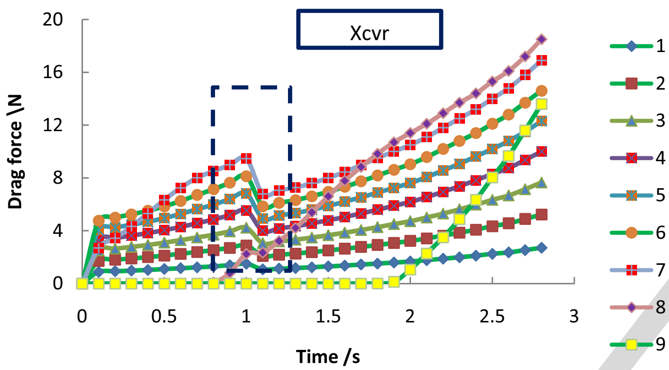
Fig. 7. Drag force histories for the single-speed case (standard case). (a) Power amplifier chip. (b) Transceiver chip.

$x$-direction (axial direction) is dominant. Hence, the results presented in this paper are only in the axial direction.

The transient drag force histories for the standard case in this paper are shown in Fig. 7(a) and (b). Drag force could be classified into two categories. For the chips covered by the molding compound initially, the drag force increases progressively along with the time. For the chips at the peripheral that are not covered by the molding compound initially, the drag force is zero before contact with the molding compound and then increases to its peak rapidly after contact with the molding compound.




(a)




(b)

Fig. 8. Drag force histories for the multispeed case. (a) Power Amplifier chip. (b) Transceiver chip.

The transient histories of the drag force for the multispeed method on the two dies, PA and Xcvr, are shown in Fig. 8. The drag force experiences a sudden drop from 1 to 1.1 s for both PA and Xcvr, as shown in the dotted box. Through applying multispeed method, the maximum drag force on PA is significantly reduced by 34.4% and on Xcvr is 35.4%.

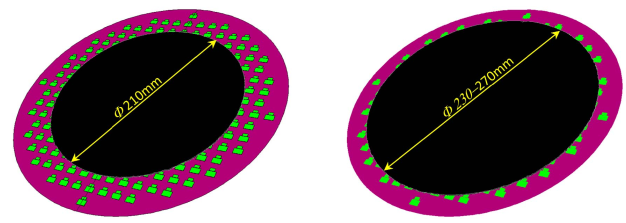
These findings suggest that the filling speed of the top mold chase is one of the key factors in the molding simulation. Appropriate filling speed profile will ensure the reduction of the drag force.

## *B. Optimizing the Initial Diameter of the Molding Compound*

The initial diameter of the molding compound investigated in this paper is shown in Fig. 9. The initial diameter of the molding compound is varied from 210 to 270 mm. The other parameters are the same as the standard case.

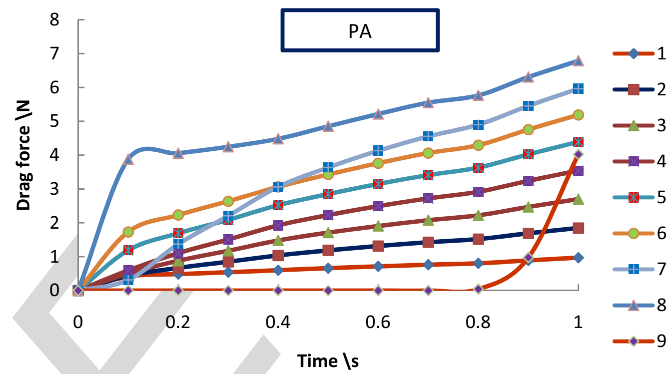
The transient drag force histories for the initial diameter of the molding compound enlarged to 250 mm are shown in Fig. 10. The drag force acceleration of the die at the peripheral is greater than for other dies. The maximum drag force on the last die, however, does not surpass the drag force on dies 5–8 at the end of filling stage. This is mainly due to the molding time being shorter in this case. The molding time is significantly reduced by $> 50\%$, comparing with the standard case. Although the initial drag force and the acceleration are larger than the other dies, the molding time is not sufficient for the drag force to increase significantly. Through enlarging the initial diameter of molding compound, the maximum drag force on PA is significantly reduced by 35.1% and on Xcvr is 23.6%. Comparison of the maximum drag force for the different initial diameters of the molding compound is listed in Table II. The results show that the drag force increases to its peak at the initial diameter of molding compound is 230 mm and then drops as the initial diameter of molding compound increases.

This finding shows that optimizing the initial diameter of the molding compound could be a possible way to solve the die shift issues because of the mold flow effect.

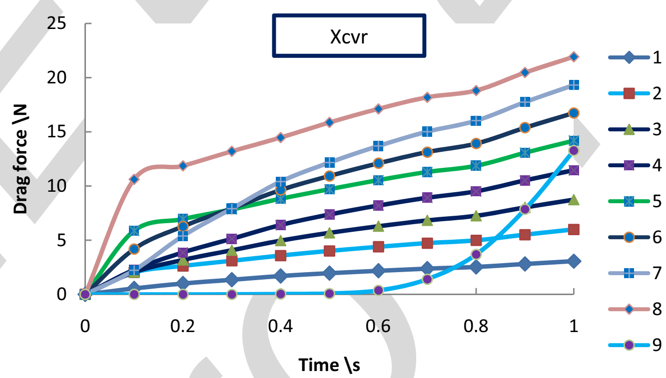



(a) (b)

Fig. 9. Initial diameter of the molding compound. (a) Original dispensing pattern (standard case). (b) Enlarged dispensing pattern.




(a)




(b)

Fig. 10. Drag force histories for enlarged diameter of the molding compound. (a) Power Amplifier chip. (b) Transceiver chip.

TABLE II
COMPARISON OF THE MAXIMUM DRAG FORCE FOR THE DIFFERENT INITIAL DIAMETERS OF THE MOLDING COMPOUND

| Diameter of the molding compound(mm) | Max drag force (N) | | Reduction | |
|---|---|---|---|---|
| | PA | Xcvr | PA | Xcvr |
| 210(Standard case) | 10.46 | 28.66 | | |
| 230 | 13.39 | 37.49 | -28.01% | -30.81% |
| 250 | 6.79 | 21.90 | 35.09% | 23.59%. |
| 270 | 4.53 | 13.71 | 56.69% | 52.16% |

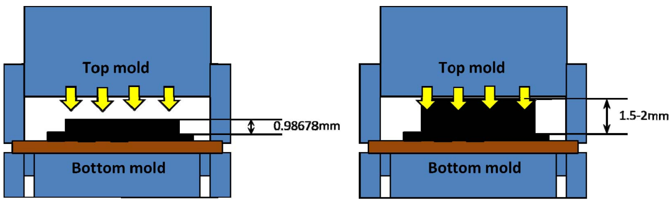



Fig. 11. Sketch of the thickness of the molding compound. (a) Original thickness (standard case). (b) Enlarged thickness.

### C. Increasing the Thickness of the Molding Compound

Varying the thickness of molding compound could lead to different drag force values. In this paper, the thickness of molding compound is varied from 0.98 to 2 mm, comparing with the standard case in solution 1, as shown in Fig. 11. The other parameters are the same as the standard case.

The drag force histories for molding compound increased to 1.8 mm are shown in Fig. 12. Comparing with the standard case, the drag force is significantly reduced. Through increasing the thickness of the molding compound, the maximum drag force on PA is significantly reduced by 84.7% and on Xcvr is 83.6%. Comparison of the maximum drag force for the different molding compound thicknesses is listed in Table III.

This finding reveals that the initial thickness of the molding compound also has a strong effect on the drag force. Increasing the thickness of molding compound could be a possible solution in solving die shift issues.

## VI. DISCUSSION

In this section, the mechanism of mold flow process will be further explained to shed some insights on how the three solutions we propose could reduce the die shift because of the mold flow effect. A sketch of the molding process is shown in Fig. 13, where $r$ is the diameter of the molding compound, $h$ is the thickness of the molding compound, $A1$ and $A2$ are the top area and the side area of the molding compound, $V1$ is the velocity of the top mold chase, and $V2$ is the axial velocity of molding compound. *V2* is assumed to be constant in this analysis because of the axi-symmetric characteristic throughout the entire filling stage.

From the point of view of mass conservation, we could deduce the following:

$$V1 \times A1 = V2 \times A2. \quad (1)$$

For $A1 = \pi r^2$ and $A2 = 2\pi rh$, the final relationship between *V2* and *V1* should be the following:

$$V2 = \frac{r}{2h} V1. \quad (2)$$

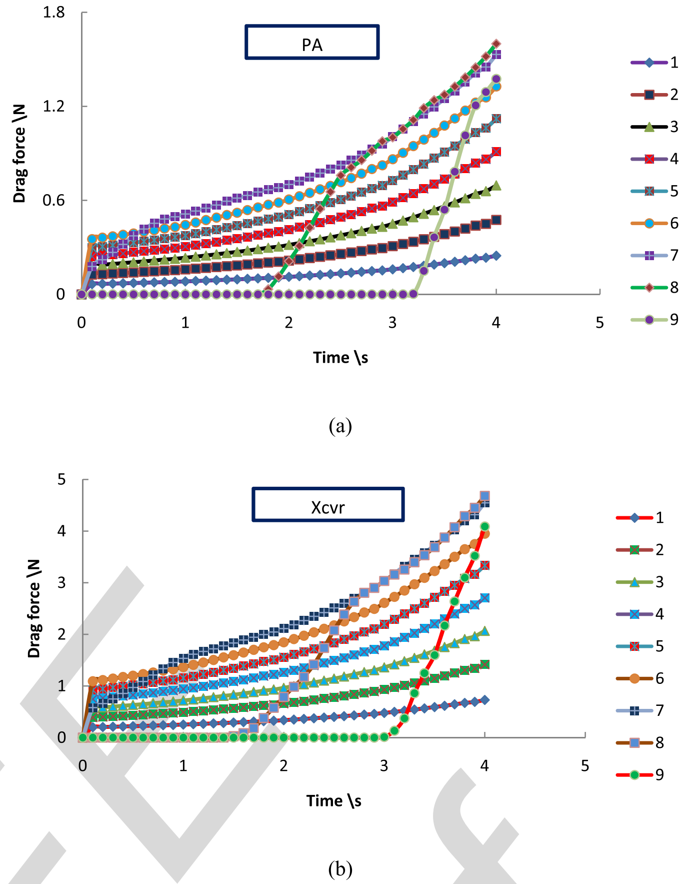



Fig. 12. Drag force histories for enlarged thickness of the molding compound. (a) Power Amplifier chip. (b) Transceiver chip.

TABLE III
COMPARISON OF THE MAXIMUM DRAG FORCE FOR THE DIFFERENT MOLDING COMPOUND THICKNESSES

| Thickness of molding compound(mm) | Max drag force (N) | | Reduction | |
|---|---|---|---|---|
| | PA | Xcvr | PA | Xcvr |
| 0.98(Standard case) | 10.46 | 28.66 | | |
| 1.5 | 3.39 | 10.90 | 67.59% | 61.97% |
| 1.8 | 1.60 | 4.68 | 84.70% | 83.67% |
| 2.0 | 1.32 | 3.91 | 87.38% | 86.36% |

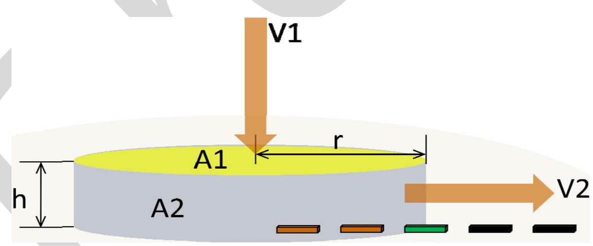



Fig. 13. Sketch of the molding process.

In the molding process, as the molding compound flows toward the peripheral, $r$ increases and $h$ decreases, while $V1$ is kept constant. From (2), this implies that $V2$ must, therefore, be of a higher value at the peripheral as compared with $V2$ closer to the center of the wafer. That is the reason why the drag forces of the last two dies at the peripheral with an initial drag force of zero surpass the drag force of other dies at the end of the filling stage.

For solution 1, $V1$ is reduced whereas the other parameters are kept constant. From (2), $V2$ will be reduced linearly along with $V1$. For solution 3, $h$ is increased whereas the other parameters are kept constant. From (2), $V2$ will be reduced inversely along with the increasing of $h$. These two solutions suggested in this paper are actually to reduce $V2$.

In solution 2, $r$ is increased whereas the other parameters are kept constant. The initial velocity $V2$ is increased. The molding time is, however, reduced because of the enlargement of the initial diameter of the molding compound. Die shift because of the fluid effect is accumulated as time goes by. Whether the die shift is increased or not depends on if the reduced time could compensate the increment of $V2$. Therefore, $V2$ and the molding time are the two key factors in reducing the die shift because of the fluid effect in the molding process.

## VII. Conclusion

The 3-D embedded wafer-level numerical simulation had the advantages of giving a deep insight into the mold flow mechanism. Important conclusion and recommendations from this paper can be summarized as follows.

1) The die shift modeling established in this paper was validated by the experimental results. Comparing with the CTE effect, the mold flow effect was less significant in the die shift phenomenon. Further work will be carried out to reduce the die shift because of the CTE effect, which was the dominating effect in die shift.
2) Filling speed, molding time, initial thickness of the molding compound, and initial diameter of the molding compound were controllable parameters in the molding process. Minimum die shift during the molding process could be obtained by optimizing these parameters.
3) Decreasing the filling speed, increasing the thickness of molding compound, and enlarging the initial diameter of the molding compound to a certain extent could be the possible solutions in reducing the drag force because of the flow effect. Although increasing the thickness of the molding compound was an effective way to reduce the drag force, its cost was the additional volume of the molding compound.
4) Two kinds of drag force behaviors were discovered in the molding process. For the chips covered by the molding compound initially, drag force was increased progressively. For the chips at the peripheral edge, which were not covered by the molding compound initially, drag force was zero before contact with the molding compound and then increased to its peak rapidly after contact with the molding compound.
5) $V2$ and the molding time were the two key factors in reducing the die shift because of the fluid effect in the molding process.
6) Combining the former Institute of Microelectronics (IME)'s research [9], we can draw a conclusion that, reducing the filling speed of the top chase, increasing the thickness of the molding compound, optimizing the initial diameter of the molding compound, selecting lower viscosity molding compound material, and using die with large surface area and low die thickness could reduce the die shift in the molding process.

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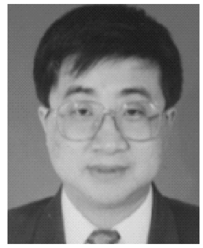

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# Investigation on Die Shift Issues in the 12-in Wafer-Level Compression Molding Process

Lin Bu, Siowling Ho, Sorono Dexter Velez, Taichong Chai, and Xiaowu Zhang, *Senior Member, IEEE*

***Abstract*— Die shift issues that arise in embedded wafer-level packaging because of the mold flow process is investigated in this paper, along with solution strategies to address them. The nonlinearity trend of the die shift in the experimental inspection is explained and captured by the numerical simulation with a consideration of the coefficient of thermal expansion effect coupled with the mold flow effect. Optimizing the initial diameter of molding compounds, increasing the thickness of molding compounds, and reducing the filling speed are the three solutions we demonstrate for reducing the drag force. Die shift generated by the mold flow could be reduced by optimizing these controllable parameters.**

***Index Terms*— Coefficient of thermal expansion (CTE), die shift, embedded water-level packaging (eWLP), mold flow effect, nonlinear.**

## I. Introduction

RECENTLY, embedded wafer-level packaging (eWLP) is evolving rapidly in the semiconductor industry, especially for usage in portable devices such as small modules for mobile phone applications. Because of its high density integration, low profile package, and high yield, eWLP will play a bigger role in future 3-D integrated circuit [1]. One of the biggest processing issues in eWLP technology is die shift in 12-in wafer-level molding process. In the die shift problem, the die is not swept completely away from their original position. Instead, a slight shift in position is observed. This slight shift in die location creates problems for subsequent wafer processes, such as the formation of redistribution lines. A major contributing factor of die shift is the thermal expansion of polymeric molding tape, because of its high coefficient of thermal expansion (CTE) value ($>35$ ppm/K) in combination with the high molding temperature.

Significant results were achieved in previous researches, focusing on die shift issues arising from the CTE effect. Gaurav *et al*. [2] constructed a finite-volume model to investigate various strategies in obtaining low die shift values. They found that low CTE and low cure shrinkage mold compound materials are mandatory to achieve low die shift values during wafer molding. Aditya *et al*. [3] carried out process optimization to reduce the die shift, resulting in a significant reduction ($\sim 80\%$) in die shift. Die shift was further characterized in terms of molding compounds and carrier types, which contribute to CTE effect, by Kim *et al*. [4]. The behavior of die shift was significantly affected by the material properties of molding compounds as well as that of carriers. Their findings revealed that material properties of both the molding compound and the carrier should be considered carefully to minimize the magnitude of die shift. Khong *et al.* [5] established a 2-D transient model to investigate the wafer-level molding process. They found that the local shear rate is increasing linearly from the center of the wafer to the outermost die. The die shift is inversely proportional to the die thickness for wafer-level molding. Mazuir *et al.* [6] studied the effect of the adhesion between thin silicon dies and the adhesive carrier through die shear measurements. Through optimizing the pick and place parameters, it is possible to reduce the die shift from 600 to 30 $\mu$m. This improvement leads to considerable reduction in the risk to failure in the photolithography, the wafer-to-wafer alignment and the through mold via steps. Gaurav *et al.* [7] carried out the parametric studies on thermal release temperatures and molding temperatures. The thermal release temperatures range from 393.15 to 573.15 K. The highest thermal release temperature molding tape has highest associated adhesive strength. Using the highest adhesive strength tape leads to a reduction in die shift during the wafer molding process. Reducing the molding temperature also leads to reduction in die shift during wafer molding. Molding temperatures ranging from 398.15 to 448.15 K are evaluated. A molding temperature of 423.15 K is found to reduce die shift and also leads to excellent mold ability.

In the experimental inspection, die shift is found to be nonlinear at the die or the two dies at the peripheral. Die shift because of the CTE effect, however, exhibits a linear trend in the numerical simulation. Hence, other factors must have an effect on the die shift formulation. In this paper, the flow effect is investigated and the nonlinear trend is captured in the numerical simulation. A conclusion could be drawn that the die shift phenomenon is a joint effort of CTE effect and mold flow effect. Three strategies are proposed to reduce the die shift because of the flow effect.

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## II. Package Description

Institute of Microelectronics at the Agency for Science, Technology, and Research (A*STAR), Singapore and its industry partners developed an embedded device technology, based

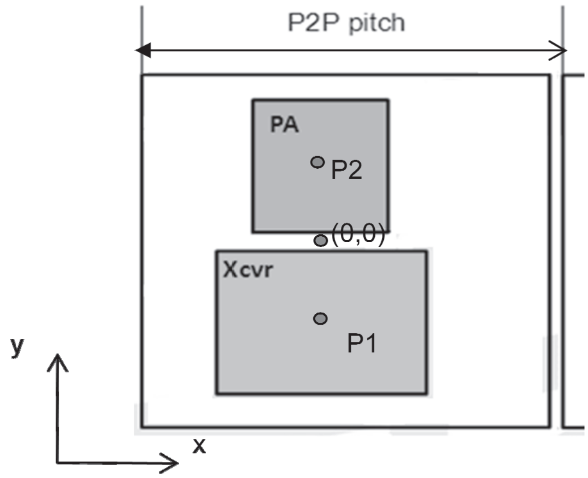



Fig. 1. Schematic plot of package design.

TABLE I
PACKAGE DETAILS

| Component | Package design |
|---|---|
| Transceiver (Xcvr) | 9.0x6.0x0.3mm |
| | P1 (0, -1.65mm) |
| Power Amplifier (PA) | 5.0x3.0x0.3mm |
| | P2 (0, 3.15mm) |

on a molded 12-in reconfigured wafer. A schematic plot of package design is shown in Fig. 1. The package size is 15 × 15 mm with a package thickness of 550 $\mu$m, and the size of the two dies are 9 × 6 mm [designated as transceiver (Xcvr)] and 5 × 3 mm [designated as power amplifier (PA)], with both 300-$\mu$m thick. The specifications of packages are listed in Table I. The gap between the big die and small die is 30 $\mu$m.

## III. MODELING

To further understand the die shift issues because of the mold flow effect in the molding process, computational fluid dynamics (CFD) simulation is a valuable tool. Establishing a validated model is, however, a challenging task. In this paper, a 3-D finite-volume model is established, as shown in Fig. 2. Molding compound flows past the chips during the molding process. The melting front is tracked by volume of fluid method, which was proposed by Hirt and Nichols [8]. There are four reconstructed methods in FLUENT software, which are modified HRIC, QUICK, CI CSAM, and compressive and geo-reconstruct. Geo-reconstruct methodology is regarded as the most accurate method in simulating the two-phase flows. Therefore, geo-reconstruct methodology is adopted in this paper. The compression motion of the top mold chase is controlled using dynamic mesh technique of FLUENT.

The modeling consists of the following assumptions.

1) A 3-D time-dependent analysis will be performed on a numerical model of the reconfigure wafer with fully populated two-die packages.

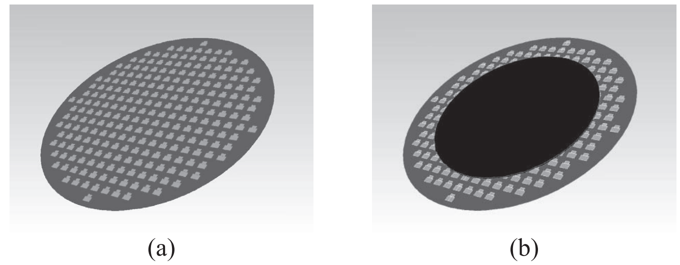



Fig. 2. CFD model of the reconfigured wafer with fully populated two-die packages. (a) Without molding compound. (b) With molding compound.

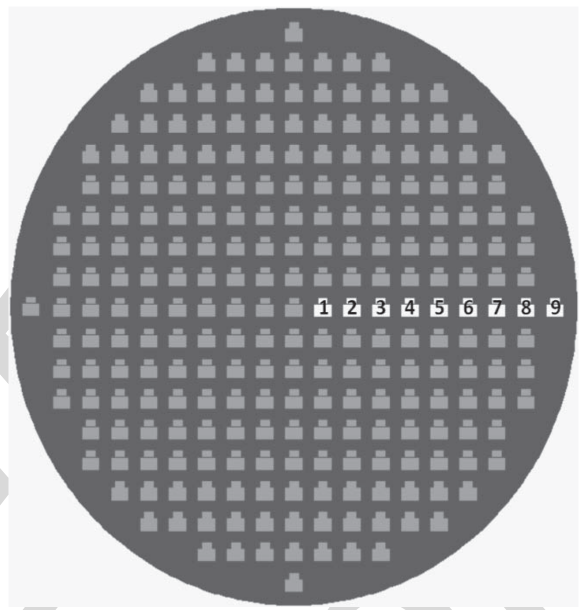



Fig. 3. Monitoring chips.

2) The mold compound is modeled with a shear-rate-dependent viscosity obeying the cross model.

3) Molding compound is assumed to be fully melted at the initial time.

## IV. VALIDATION

To benchmark the modeling methodology developed in this paper, the numerical results are compared with the experimental results. From the previous studies [9], the compression mold flow exhibits an axi-symmetric pattern throughout the entire filling stage, such that the dies at the same radial locations experience the similar drag force. Therefore, a series of dies having the different radial positions was investigated in the previous research, as shown in Fig. 3.

The benchmarking solution can be categorized into three steps. Initially, using the commercial software FLUENT to perform the mold flow simulation, then the output of the mold flow results are put into ABAQUS to conduct the mechanical simulation. In consideration of the die shift effect attributed by mold flow, a finite-element model consisting of the dies, mold tape, and mold plate is built. The pressure distribution on the walls of the dies is extracted from FLUENT and pressure distribution map is subsequently applied on the surfaces of the dies in ABAQUS. The die shift attributed by CTE and

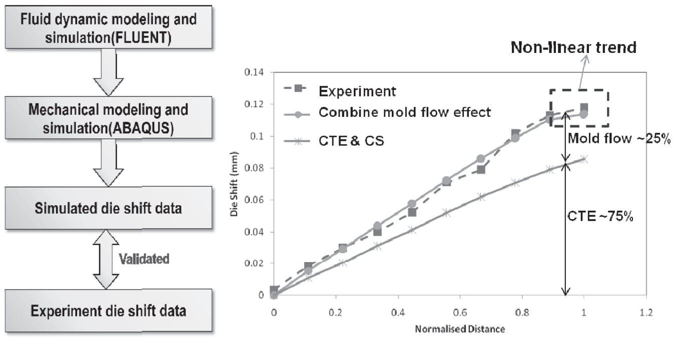



Fig. 4. Comparison of the experimental and numerical results.

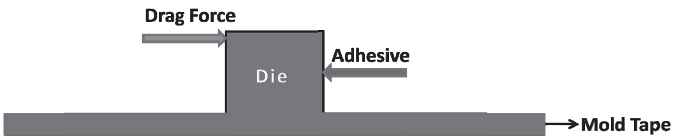



Fig. 5. Schematic plot of forces acting on the dies.

chemical shrinkage is obtained from a separate finite-element model. The simulated die shift data are obtained in this step from the outputs of ABAQUS. The comparison of the experimental and the simulation results is shown in Fig. 4. The nonlinear trend is well captured by the simulation. It can be found that the simulated results match well with the experimental results. Though the effect of mold flow could not be neglected, CTE effect is still the dominating effect in die shift. Around 25% of die shift is contributed by the mold flow effect and 75% by the CTE effect.

## V. Results

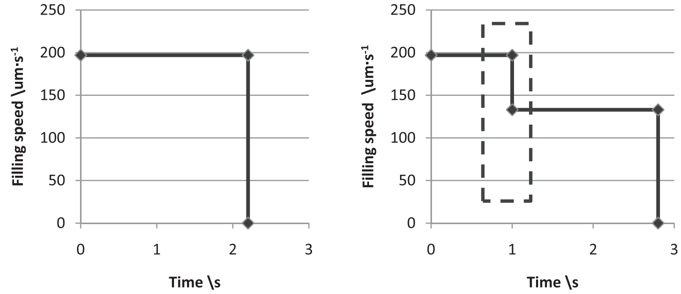
The forces acting on the dies, i.e., drag force versus adhesive force, are shown in Fig. 5. Once the drag force exceeds adhesive force, die starts to slide away from their original position [9]. A flow drag force is, however, below adhesive force in this paper and a slight shift in position is occurred. To further investigate the die shift because of the mold flow effect, the darg force exerted on the dies must be studied.

Filling speed of the top mold chase, initial thickness, and diameter of molding compound are several controllable parameters, which could easily be changed in the molding process without additional cost. In this paper, the variations of these parameters are investigated to see their affects on the drag force.

### *A. Reducing the Filling Speed of the Top Chase*

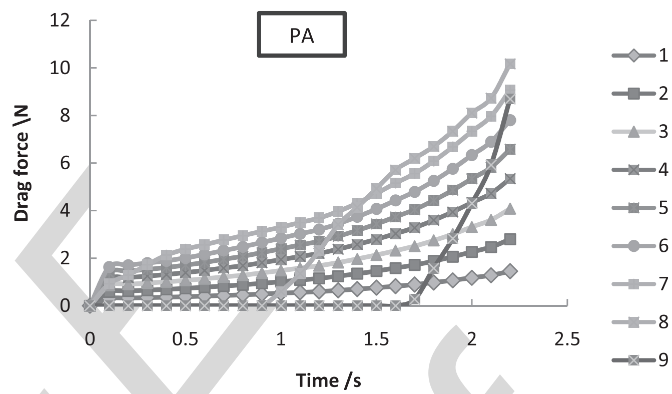
Two kinds of velocity profiles are investigated in this paper, as shown in Fig. 6(a) and (b). In the single-speed method, the filling speed is 197 $\mu$m/s. The thickness of the molding compound is 0.98 mm and the initial diameter of the molding compound is 210 mm. This case is set as a standard case in this paper.

In the multispeed method, the filling speed is initially at 197 $\mu$m/s and subsequently reduces to 133 $\mu$m/s at 1 s. For the chips investigated in this paper, the drag force in the

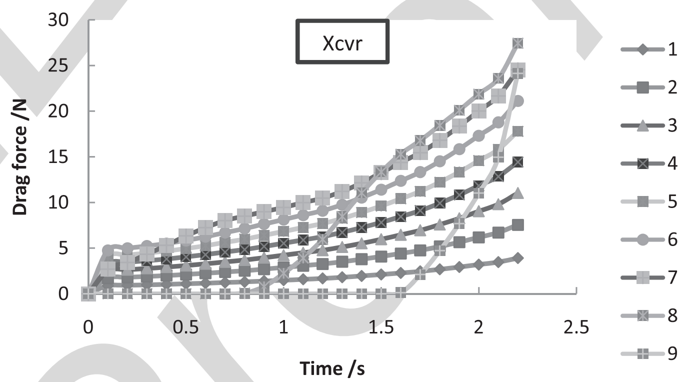



(a) (b)

Fig. 6. Velocity profiles of the filling speed. (a) Single speed (standard case). (b) Multispeed.




(a)

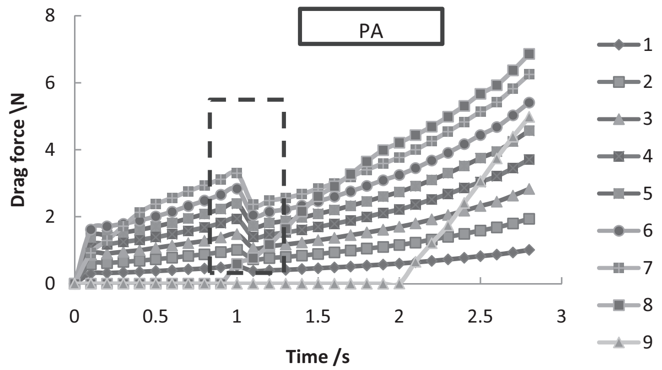



(b)

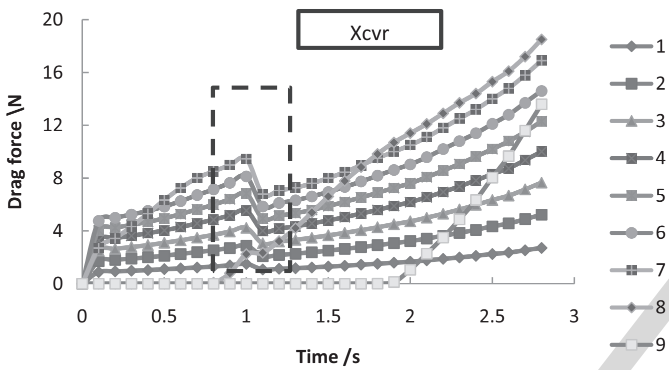
Fig. 7. Drag force histories for the single-speed case (standard case). (a) Power amplifier chip. (b) Transceiver chip.

$x$-direction (axial direction) is dominant. Hence, the results presented in this paper are only in the axial direction.

The transient drag force histories for the standard case in this paper are shown in Fig. 7(a) and (b). Drag force could be classified into two categories. For the chips covered by the molding compound initially, the drag force increases progressively along with the time. For the chips at the peripheral that are not covered by the molding compound initially, the drag force is zero before contact with the molding compound and then increases to its peak rapidly after contact with the molding compound.

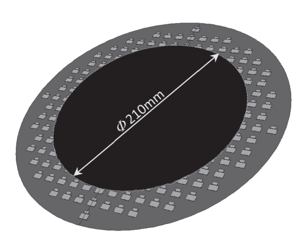



(a)

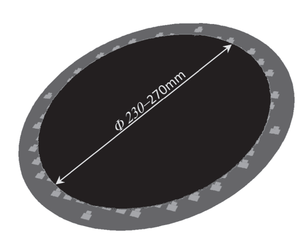



(b)

Fig. 8. Drag force histories for the multispeed case. (a) Power Amplifier chip. (b) Transceiver chip.

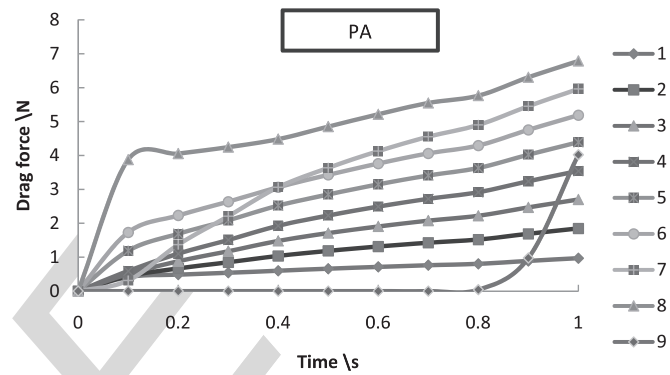



(a)

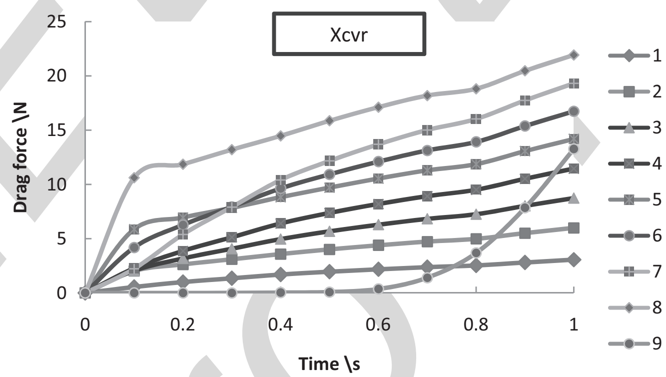



(b)

Fig. 9. Initial diameter of the molding compound. (a) Original dispensing pattern (standard case). (b) Enlarged dispensing pattern.




(a)




(b)

Fig. 10. Drag force histories for enlarged diameter of the molding compound. (a) Power Amplifier chip. (b) Transceiver chip.

The transient histories of the drag force for the multispeed method on the two dies, PA and Xcvr, are shown in Fig. 8. The drag force experiences a sudden drop from 1 to 1.1 s for both PA and Xcvr, as shown in the dotted box. Through applying multispeed method, the maximum drag force on PA is significantly reduced by 34.4% and on Xcvr is 35.4%.

These findings suggest that the filling speed of the top mold chase is one of the key factors in the molding simulation. Appropriate filling speed profile will ensure the reduction of the drag force.

### *B. Optimizing the Initial Diameter of the Molding Compound*

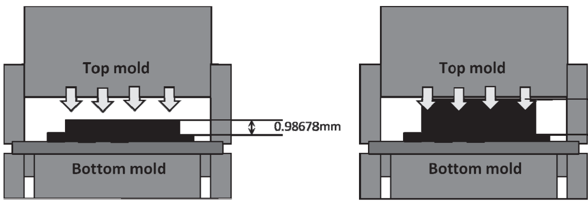
The initial diameter of the molding compound investigated in this paper is shown in Fig. 9. The initial diameter of the molding compound is varied from 210 to 270 mm. The other parameters are the same as the standard case.

The transient drag force histories for the initial diameter of the molding compound enlarged to 250 mm are shown in Fig. 10. The drag force acceleration of the die at the peripheral is greater than for other dies. The maximum drag force on the last die, however, does not surpass the drag force on dies 5–8 at the end of filling stage. This is mainly due to the molding time being shorter in this case. The molding time is significantly reduced by $> 50\%$, comparing with the standard case. Although the initial drag force and the acceleration are larger than the other dies, the molding time is not sufficient for the drag force to increase significantly. Through enlarging the initial diameter of molding compound, the maximum drag force on PA is significantly reduced by 35.1% and on Xcvr is 23.6%. Comparison of the maximum drag force for the different initial diameters of the molding compound is listed in Table II. The results show that the drag force increases to its peak at the initial diameter of molding compound is 230 mm and then drops as the initial diameter of molding compound increases.

This finding shows that optimizing the initial diameter of the molding compound could be a possible way to solve the die shift issues because of the mold flow effect.

TABLE II
COMPARISON OF THE MAXIMUM DRAG FORCE FOR THE DIFFERENT INITIAL DIAMETERS OF THE MOLDING COMPOUND

| Diameter of the molding compound(mm) | Max drag force (N) | | Reduction | |
|---|---|---|---|---|
| | PA | Xcvr | PA | Xcvr |
| 210(Standard case) | 10.46 | 28.66 | | |
| 230 | 13.39 | 37.49 | -28.01% | -30.81% |
| 250 | 6.79 | 21.90 | 35.09% | 23.59%. |
| 270 | 4.53 | 13.71 | 56.69% | 52.16% |




(a) (b)

Fig. 11. Sketch of the thickness of the molding compound. (a) Original thickness (standard case). (b) Enlarged thickness.

### C. Increasing the Thickness of the Molding Compound

Varying the thickness of molding compound could lead to different drag force values. In this paper, the thickness of molding compound is varied from 0.98 to 2 mm, comparing with the standard case in solution 1, as shown in Fig. 11. The other parameters are the same as the standard case.

The drag force histories for molding compound increased to 1.8 mm are shown in Fig. 12. Comparing with the standard case, the drag force is significantly reduced. Through increasing the thickness of the molding compound, the maximum drag force on PA is significantly reduced by 84.7% and on Xcvr is 83.6%. Comparison of the maximum drag force for the different molding compound thicknesses is listed in Table III.

This finding reveals that the initial thickness of the molding compound also has a strong effect on the drag force. Increasing the thickness of molding compound could be a possible solution in solving die shift issues.

## VI. DISCUSSION

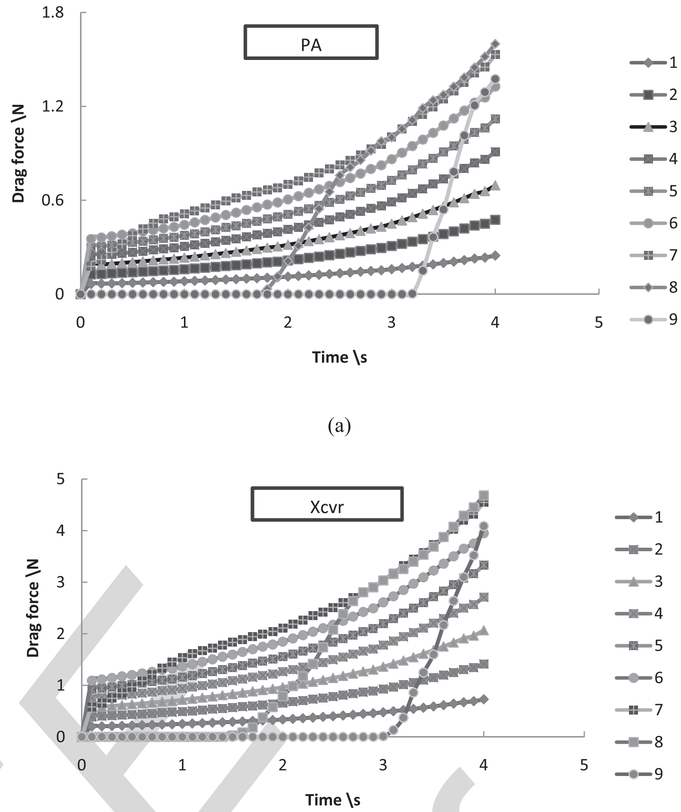
In this section, the mechanism of mold flow process will be further explained to shed some insights on how the three solutions we propose could reduce the die shift because of the mold flow effect. A sketch of the molding process is shown in Fig. 13, where $r$ is the diameter of the molding compound, $h$ is the thickness of the molding compound, $A1$ and $A2$ are the top area and the side area of the molding compound, $V1$ is the velocity of the top mold chase, and $V2$ is the axial velocity of molding compound. *V2* is assumed to be constant in this analysis because of the axi-symmetric characteristic throughout the entire filling stage.

From the point of view of mass conservation, we could deduce the following:

$$V1 \times A1 = V2 \times A2. \tag{1}$$

For $A1 = \pi r^2$ and $A2 = 2\pi rh$, the final relationship between *V2* and *V1* should be the following:

$$V2 = \frac{r}{2h} V1. \tag{2}$$




(a)

(b)

Fig. 12. Drag force histories for enlarged thickness of the molding compound. (a) Power Amplifier chip. (b) Transceiver chip.

TABLE III
COMPARISON OF THE MAXIMUM DRAG FORCE FOR THE DIFFERENT MOLDING COMPOUND THICKNESSES

| Thickness of molding compound(mm) | Max drag force (N) | | Reduction | |
|---|---|---|---|---|
| | PA | Xcvr | PA | Xcvr |
| 0.98(Standard case) | 10.46 | 28.66 | | |
| 1.5 | 3.39 | 10.90 | 67.59% | 61.97% |
| 1.8 | 1.60 | 4.68 | 84.70% | 83.67% |
| 2.0 | 1.32 | 3.91 | 87.38% | 86.36% |

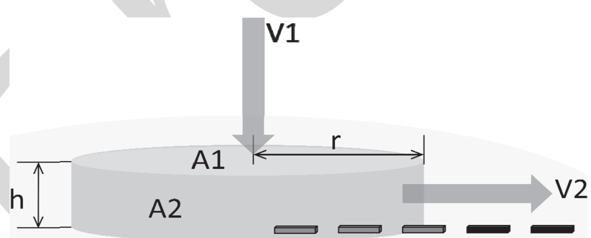



Fig. 13. Sketch of the molding process.

In the molding process, as the molding compound flows toward the peripheral, $r$ increases and $h$ decreases, while $V1$ is kept constant. From (2), this implies that $V2$ must, therefore, be of a higher value at the peripheral as compared with $V2$ closer to the center of the wafer. That is the reason why the drag forces of the last two dies at the peripheral with an initial drag force of zero surpass the drag force of other dies at the end of the filling stage.

For solution 1, $V1$ is reduced whereas the other parameters are kept constant. From (2), $V2$ will be reduced linearly along with $V1$. For solution 3, $h$ is increased whereas the other parameters are kept constant. From (2), $V2$ will be reduced inversely along with the increasing of $h$. These two solutions suggested in this paper are actually to reduce $V2$.

In solution 2, $r$ is increased whereas the other parameters are kept constant. The initial velocity $V2$ is increased. The molding time is, however, reduced because of the enlargement of the initial diameter of the molding compound. Die shift because of the fluid effect is accumulated as time goes by. Whether the die shift is increased or not depends on if the reduced time could compensate the increment of $V2$. Therefore, $V2$ and the molding time are the two key factors in reducing the die shift because of the fluid effect in the molding process.

## VII. Conclusion

The 3-D embedded wafer-level numerical simulation had the advantages of giving a deep insight into the mold flow mechanism. Important conclusion and recommendations from this paper can be summarized as follows.

1) The die shift modeling established in this paper was validated by the experimental results. Comparing with the CTE effect, the mold flow effect was less significant in the die shift phenomenon. Further work will be carried out to reduce the die shift because of the CTE effect, which was the dominating effect in die shift.
2) Filling speed, molding time, initial thickness of the molding compound, and initial diameter of the molding compound were controllable parameters in the molding process. Minimum die shift during the molding process could be obtained by optimizing these parameters.
3) Decreasing the filling speed, increasing the thickness of molding compound, and enlarging the initial diameter of the molding compound to a certain extent could be the possible solutions in reducing the drag force because of the flow effect. Although increasing the thickness of the molding compound was an effective way to reduce the drag force, its cost was the additional volume of the molding compound.
4) Two kinds of drag force behaviors were discovered in the molding process. For the chips covered by the molding compound initially, drag force was increased progressively. For the chips at the peripheral edge, which were not covered by the molding compound initially, drag force was zero before contact with the molding compound and then increased to its peak rapidly after contact with the molding compound.
5) $V2$ and the molding time were the two key factors in reducing the die shift because of the fluid effect in the molding process.
6) Combining the former Institute of Microelectronics (IME)'s research [9], we can draw a conclusion that, reducing the filling speed of the top chase, increasing the thickness of the molding compound, optimizing the initial diameter of the molding compound, selecting lower viscosity molding compound material, and using die with large surface area and low die thickness could reduce the die shift in the molding process.

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