A THREE-DIMENSIONAL CAE MOLDING OF MICROCHIP ENCAPSULATION

Ya-Yuen Chou [1], Han-Po Yeh [1], Hsien-Sen Chiu [1], Chau-Kai Yu[1], and Rong-Yeu Chang[2]

1. *CoreTech System (Moldex3D) Co., Ltd., ChuPei City, Hsinchu, Taiwan*
2. *Dept. of Chemical Engineering, National Tsing-Hua University, Hsinchu, Taiwan*

Abstract

In the packaging of plastic-encapsulated microelectronics (PEM), microchip encapsulation has been the dominant technique for encapsulation processes. With the tendency of the technologies continuously moving toward smaller scale and higher density, the existed defects problems during fabrication become more and more important. Among those problems, wire sweep and paddle shift are the most common. In this study, an integrated CAE technology which gives a comprehensive solution for microchip encapsulation has been developed. By using this technology, wire sweep and paddle shift predictions under different molding conditions can be obtained, and the simulation results also demonstrate the feasibility of our technology for practitioners to analyze their mold designs for microchip encapsulation.

Introduction

In the packaging of plastic-encapsulated microelectronics (PEM), transfer molding is the dominant technique for encapsulation processes, especially for the microchip encapsulation. With the tendency of microchip encapsulation technologies continuously moving toward smaller scale and higher density, the existed defects problems during fabrication becomes more and more important. Moreover, improper selection of processing conditions, complexity of material properties during processing, and leadframe layout or molding design, raise manufacturing challenges. Among those problems, stress-induced problems such as wire sweep and paddle shift are the most common in microchip encapsulation processes. The viscous drag force on wires exerted by the resin melt flow causes wire sweep problem, while non-uniform loading on paddle system applied by uneven melt flow within cavities results in paddle shift problem.

Conventionally, these problems can only be solved by means of using “trial-and-error” method in molding design optimization. However, it is difficult because of the complex interactions between fluid flow, heat transfer and polymerization of epoxy molding compound (EMC). Over the last decade, progress in both hardware and software has made computer-aided-engineering (CAE) an effective tool for analyzing the complicated physical phenomena inherent in processes of plastic encapsulation of microchips.

In this paper, a true 3D CAE technology is developed to evaluate the design of microchip encapsulation. As an integrated technology to connect pre-process, filling and curing analyses, structure analysis and post-process, it gives a comprehensive solution for microchip encapsulation. In pre-process, parameterized method is provided to create the wire for minimizing efforts in meshing; in filling stage, a precise prediction of the branching effects caused by wire and paddle is shown to help users evaluate the design. Moreover, the information about the welding line, the position of air trap, the velocity vector distribution, and the transfer pressure are obtained. The volumetric shrinkage of thermoset material is also considered in filling analysis for subsequent warpage analysis. Furthermore, in curing analysis, the process of curing and the curing rate can both be estimated.

For predictions about wire sweep and paddle shift problems, prerequisite data is obtained from filling results and then is incorporated into subsequent analyses by other structural analysis software. By using this integrated CAE technology, the physical phenomenon for different molding design of microchip encapsulation can be easily obtained, and the simulation results also demonstrate the feasibility of our technology for practitioners to analyze their mold designs for microchip encapsulation.

Three-Dimensional Flow Analysis

***Governing Equations*:**

Theoretically, microchip encapsulation process is a three-dimensional, transient, reactive problem with moving resin front. The non-isothermal resin flow in mold cavity can be mathematically described by the following equations [1]:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \rho \mathbf{u} = 0 \tag{1}$$

$$\frac{\partial}{\partial t}(\rho \mathbf{u}) + \nabla \cdot (\rho \mathbf{u}\mathbf{u} - \boldsymbol{\sigma}) = \rho \mathbf{g} \tag{2}$$

$$\boldsymbol{\sigma} = -p\mathbf{I} + \eta\left(\nabla \mathbf{u} + \nabla \mathbf{u}^T\right) \tag{3}$$

$$\rho C_P\left(\frac{\partial T}{\partial t} + \mathbf{u} \cdot \nabla T\right) = \nabla(\mathbf{k}\nabla T) + \Phi \tag{4}$$

where $\mathbf{u}$ is the velocity vector, T is the temperature, t is the time, p is the pressure, $\boldsymbol{\sigma}$ is the total stress tensor, ρ is the fluid density, k is the thermal conductivity, C_p is the specific heat, and Φ is the energy source tem. In this work, the energy source contains two contributions:

$$\Phi = \eta\dot{\gamma} + \dot{\alpha}\Delta H \qquad (5)$$

where η is the viscosity, $\dot{\gamma}$ is the magnitude of the rate of deformation tensor, $\dot{\alpha}$ is the conversion rate and ΔH is the exothermic heat of polymerization.

***Chemorheology*:**

The curing reaction of epoxy resins has received much attention using different analyses. In this work, we apply the combined model proposed by Kamal and Ryan [2] to investigate the curing kinetics of the given EMC because of its ability to accurately predict the experimental data. The combined model can be expressed as follows:

$$\frac{d\alpha}{dt} = \left(k_1 + k_2\alpha^m\right)\left(1-\alpha\right)^n \qquad (6)$$

$$k_1 = A_1 \exp\left(-\frac{E_1}{RT}\right) \qquad (7)$$

$$k_2 = A_2 \exp\left(-\frac{E_2}{RT}\right) \qquad (8)$$

where α is the conversion of reaction, A_1, A_2, E_1, E_2, m, n are model parameters.

During the curing process, the viscosity of epoxy resins changes with temperature and conversion rate. The Castro-Macosko model [3] is adopted to describe the rheological properties of epoxy resins:

$$\eta(\alpha, T) = \eta_0(T)\left(\frac{\alpha_g}{\alpha_g - \alpha}\right)^{C_1 + C_2\alpha} \qquad (9)$$

$$\eta_0(T) = A\exp\left(E_a / RT\right) \qquad (10)$$

where A, E_a, C_1, C_2 are model parameters, α_g denotes gelation conversion at which viscosity curve grows up because of the formation of three-dimensional network structure of the epoxy resins. It should be determined from experiments.

Numerical Method

The collocated cell-centered FVM (Finite Volume Method)-based 3D numerical approach developed in our previous work is further extended to simulate the mold filling in IC packaging [4]. The numerical method is basically a SIMPLE-like FVM with improved numerical stability. Furthermore, the volume-tracking method based on a fixed framework is incorporated in the flow solver to track the evolutions of melt front during molding.

Three-Dimensional Structure Analysis

***Wire Sweep Analysis*:**

To calculate the drag force exerted on the wires by the resin flow, the values of velocities and viscosity have to be determined from the mold filling simulation. The effect of wire density on the resin flow is considered according to their occupied volume in the three-dimensional filling simulation. Then, the Lamb's model is utilized to calculate the drag force as follows [5]:

$$F = \frac{C_D \rho U^2 d}{2} \qquad (10)$$

where F is the drag force per unit length, ρ is the fluid density, U is the undisturbed upstream velocity, d is the wire diameter and C_D is the drag coefficient, which can be written as:

$$C_D = \frac{8\pi}{\mathrm{Re}\left[2.002 - \ln(\mathrm{Re})\right]} \qquad (11)$$

where Re is the Reynolds number, which can be defined as:

$$\mathrm{Re} = \frac{\rho U d}{\eta} \qquad (12)$$

where η is the fluid viscosity.

An index called wire sweep index (WSI) is a commonly used parameter to determine the degree of wire deformation, which is calculated from making the largest deformation normal to the wire divided by the projected length of the wire. After the drag force calculation is done, all the relevant data will be used for wire deformation calculation. After structure analysis is done, the WSI for each wire could be calculated.

***Paddle Shift Analysis*:**

The melt pressure p during filling is governed by Eq. (3). Moreover, it exerts a net lateral force on the paddle surface. Hence the paddle shift can be obtained from the force balance:

$$\nabla\sigma + F = 0 \qquad (13)$$

where σ is the stress and F is the body force from melt pressure.

After filling analysis is done, the pressure loading on the paddle exerted by this fluid and other relevant data will be used for further paddle deformation calculation.

Results and Discussions

In this study, two most common stress-induced problems, wire sweep and paddle shift, are our main concern in the three dimensional CAE analysis for microchip encapsulation. Two cases are used for discussions about wire sweep and paddle shift phenomena respectively. First is the wire sweep analysis, and the model geometry and the layout of wires within our test model are shown in Fig. 1.

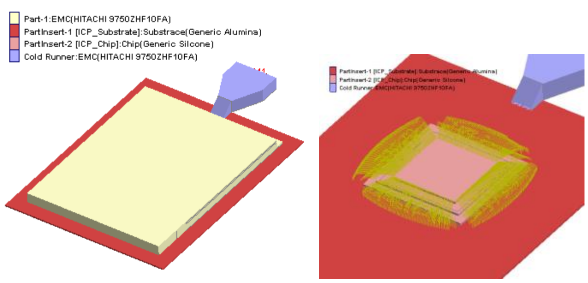
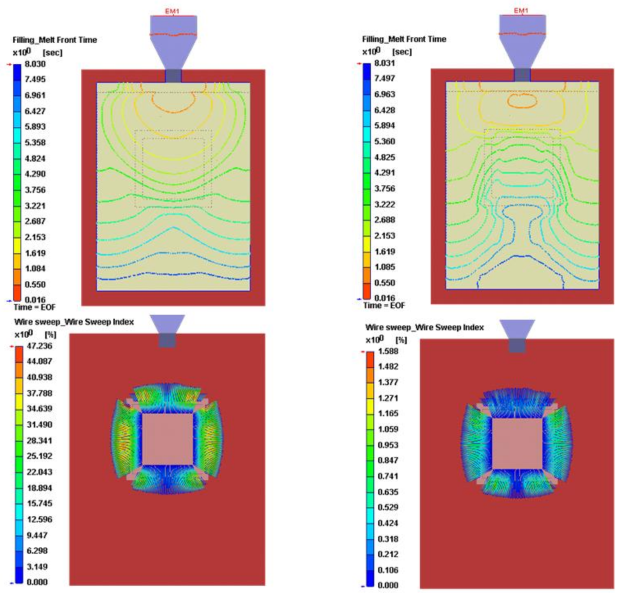


Figure 1. Geometry and wire layout of test model for wire sweep analysis

The change of the amount of wire sweep due to flow pattern change caused by upstream wires is called “wire density effect” [5]. Conventionally, wire density effect on melt flow is either modeled by means of removing the wire elements in the solid mesh or ignored during filling analyses. In our developed meshing technologies, wire density effect on melt flow is implemented by calculating the occupied volume ratio of wires within solid mesh. Therefore, the overestimated or underestimated wire density effect issues can be improved.

Accurately predicting wire sweep problems is accomplished by calculating accurate drag force on wires exerted by the resin melt flow during filling analysis. As mentioned above, the effect of wire density on the resin flow is considered according to their occupied volume within package in this work. After filling analysis is complete, the velocities and viscosity of resin flow passing through wires can then be substituted into the Lamb’s model to evaluate the drag force exerting on wires. Then, the wire sweep deformation can be calculated by launching external commercial stress solver automatically. In this paper, ANSYS is adopted. After the displacement of wire is calculated, WSI of each wire can be obtained.

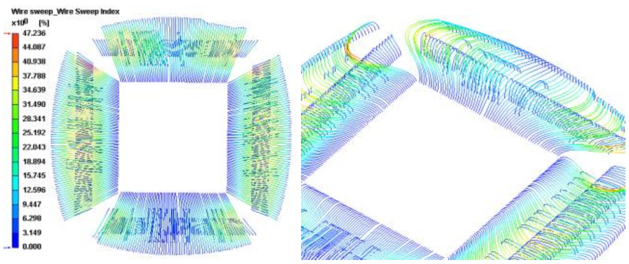
Fig. 2 shows the comparison of contour of filling pattern and WSI distribution between considering and ignoring wire density effect. From the contour of filling pattern in Fig. 2(b), we can see that since the wire density effect on melt is considered, wires form resistances to melt flow, therefore the velocities of melt near wires decrease and the flow field changes additionally, whereas the melt front remains unchanged after passing wires when wire density effect is ignored in Fig. 2(a). Moreover, a more accurate flow field result can improve the prediction of WSI.



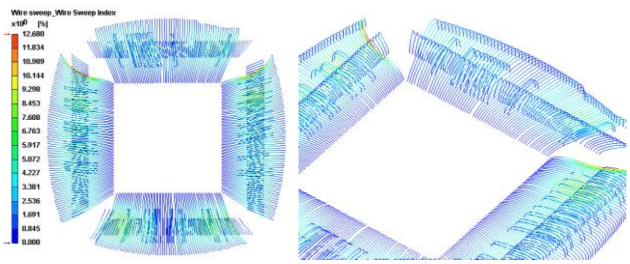
(a) (b)

Figure 2. Contour of filling pattern and wire sweep index by (a) ignoring and (b) considering wire density effect

A closer inspection of WSI is shown in Fig. 3. Generally, wire experienced higher lateral flow loading has larger deformation, thus the value of WSI is proportional to the orientation angle of the wirebond in the cavity. However, in real cases, complex layout of electrical components and wires will also affect the distribution of WSI. From Fig. 3(b), we can see that wires with maximum WSI locate at positions where melt starts to meet wires aligned against the flow direction, not at positions where wires form largest angle to the flow direction. This is because that as melt starts to meet wires aligned against the flow direction, flow velocity begins to decrease, thus reduces the velocity of melt front when melt reaches wires forming largest angle to the flow direction. Moreover, by comparing the prediction of deformed shape of wire between Fig. 3(a) and (b), it is seen that WSI is more reasonable in Fig. 3(b) by considering wire density effect before wire sweep analysis.



(a)



(b)

Figure 3. WSI distribution of wires with un-deformed (left) and deformed (right) shape by (a) ignoring and (b) considering wire density effect

An important defect caused by wire sweep is the wire short problem, which happens when excessive amount of deformation of wires during the molding process forces wires contact to each other. In our simulation results, positions with highest possibility of wire short can also be predicted by amplifying the deformation scale of wire sweep, see Fig. 4.

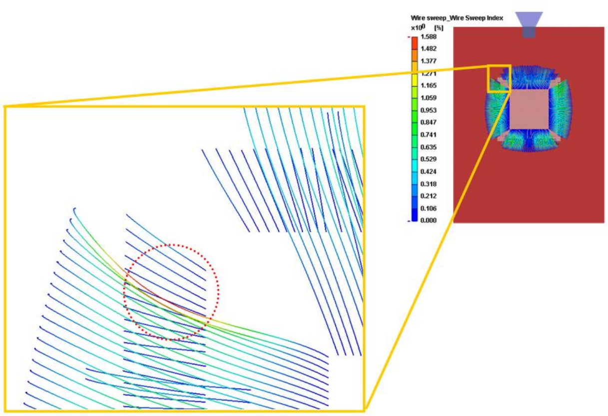


Figure 4. Predicted wire short region

Another defect problem to our interest is paddle shift. Since the paddle shift is also a flow-induced phenomenon, paddle shift analysis can be realized by incorporating structure analysis after filling analysis is done. By outputting pressure loading on paddle exerted by melt flow into commercial software, ANSYS, the deformation of paddle changes with time can be examined. Side view and top view of our test model used for paddle shift analysis are shown in Fig 5 and 6 respectively, and the predicted results could be validated by experiment results. Fig. 7 (a) ~ (c) shows the comparison of filling pattern between experiment and simulation results at distinct filling time, and the results show a close agreement. Comparison of deformed shape of paddle at end of filling between simulation and experiment results are shown in Fig. 8, and there is a coincident in position where deformed paddle exposed outside the package between these two results. Side view of deformed shape of paddle shown in Fig. 9 makes it clearer about the tendency of paddle shift. Moreover, predicted maximum deflection of paddle shift is compared to measured results, shown in Fig. 10. Therefore, from the results of filling and paddle shift analyses, the feasibility of our technology to analyze mold designs for microchip encapsulation can be demonstrated.

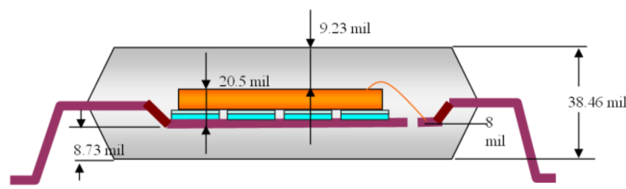
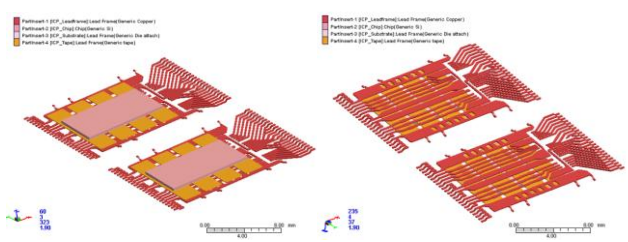
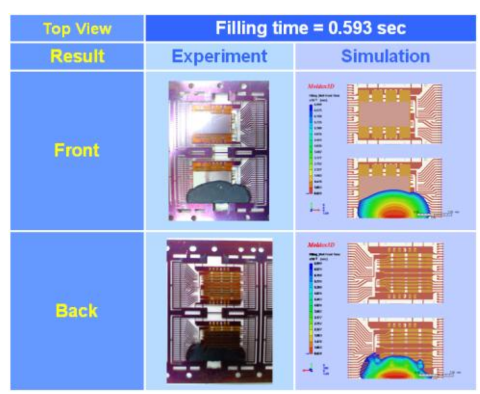


Figure 5. Side view of model geometry for paddle shift analysis

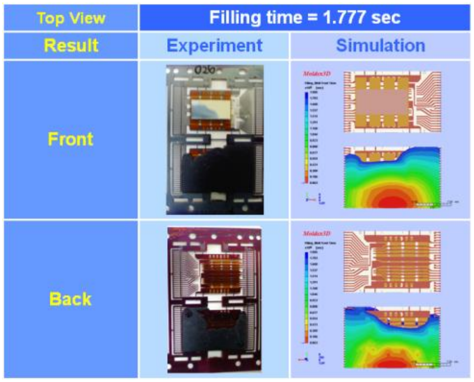


(a) Front (b) Back

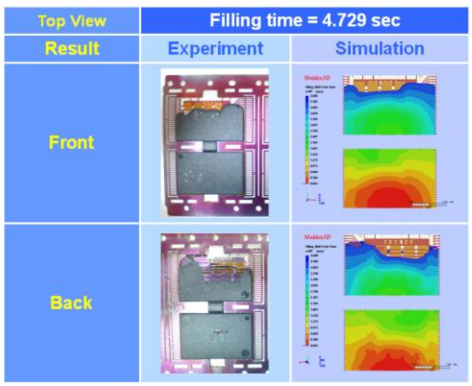
Figure 6. Top view of test model for paddle shift analysis



(a)



(b)



(c)

Figure 7. Comparison of filling pattern between experiment and simulation results at distinct filling time

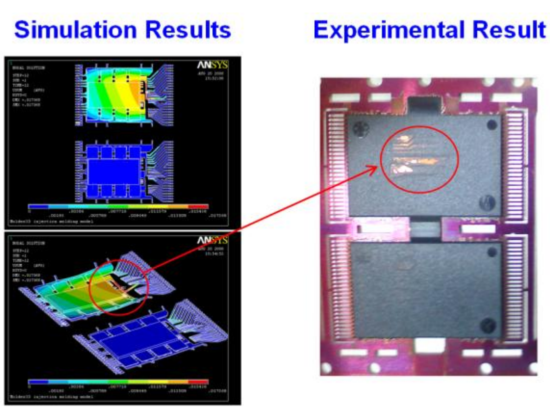
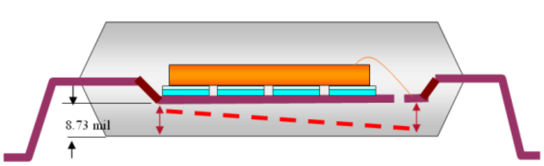
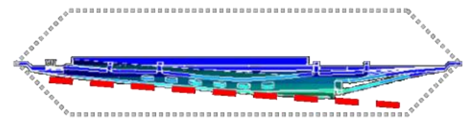


Figure 8. Comparison of deformed shape at end of filling between simulation and experiment results



(a)



(b)

Figure 9. Side view of paddle shift phenomenon:
(a) Illustration of paddle shift within package
(b) Predicted paddle shift result

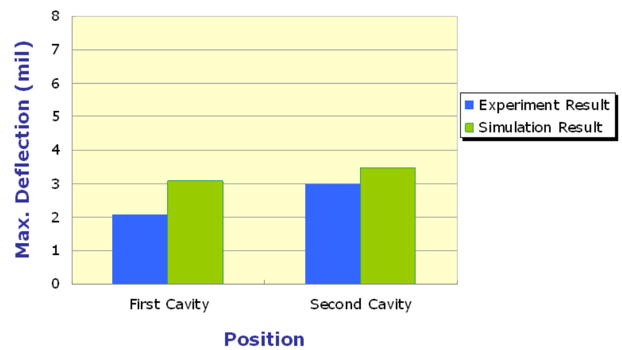


Figure 10. Comparison of maximum deflection of paddle shift between simulation and experiment results.

Conclusions

In this paper, a true 3D CAE technology is developed to evaluate the design of microchip encapsulation. Through this integrated technology, the implementation of CAE analysis from pre-process, filling and structure analyses to post-process can be realized easily. It gives a comprehensive solution for microchip encapsulation, including defect problems inspection such as wire sweep and paddle shift.

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Key Words: Microchip encapsulation, IC Package, wire sweep, paddle shift.