3D Simulation of Fine Pitch Underfill Encapsulation

Chih-Chung Hsu[2], Hsien-Sen Chiu[1], Wen-Hsien Yang[1], Rong-Yeu Chang[2]
[1]CoreTech System (Moldex3D) Co., Ltd., ChuPei City, Hsinchu, Taiwan
[2]Department of Chemical Engineering, National Tsing-Hua University, Hsinchu, Taiwan 30043, R.O.C.

ABSTRACT

The flip chip molding is much smaller than a traditional carrier-based system; the chip sits directly on the circuit board, and is much smaller than the carrier both in area and height. The short wires greatly reduce inductance, allowing higher-speed signals, and also carry heat better. However, fine pitch flip chip molding has difficulty meeting mechanical shock and prevention voids for underfill in on-site process. Applying the conventional trial-and-error method to resolve these problems is difficult and costly because of the complex interactions among fluid flow, heat transfer, structural deformation and polymerization of the underfill.

In this study, a general-purpose, 3D simulation tool is proposed to accurately track the propagation of the underfill in microchips. The capillary flow, which is influenced by the surface tension of underfill and the contact angle between bumps and substrate, of dispensing process for flip chip underfill is discussed by numerical analysis. The proposed methodology developed in this work accounts for most of the physical phenomena believed to play an important role in underfill flows. The results demonstrate not only show how an encapsulant fills an underfill gap, flowing around the bumps, but also simulate the different moving speeds of the injectior. The simulation tool provides a promising simulation solution for the microchip encapsulation process.

INTRODUCTION

Customer demand for highly sophisticated and ever-smaller electronic products has made IC packaging a challenging procedure. This trend is driving the technology toward higher packaging densities with thinner and smaller profiles, which makes the encapsulation process much more complicated and unpredictable. Flip chips have recently gained popularity among manufacturers of many small electronics where the size savings are valuable. From the initial starting C4 flip chip packages, the industry continued to improve high-performance package, including more than 10,000 in connection the spacing of less than 200 microns, the evolution of the organic material from the ceramic substrate, and the evolution from high-lead to lead-free interconnect etc.. Even so, the basis of factors that affect the packaging challenges remain, such as cost-effective manufacturing process, fine pitch interconnect within the micro-behavior. These are in the chip / wafer level miniaturization and integration issues that must be overcome[1][2].

This in turn has created a need for simulation tools that can model the transient underfill flow process and that can accurately predict the filling time, the final filling shape formed around IC chip and the occurrence of air trap around bumps for increasing the reliability of flip-chip packaging. In this study, the effect of capillary action, viscosity and surface tension on the flow behavior in the capillary underfilling process are discussed. Examples simulated by 3-D application have been shown. By using the integrated analysis, molding defects can be easily detected and moldability problems can be improved efficiently to reduce manufacturing cost and design cycle time.

IMPLEMENTATION DETAILS

Filling process can be described by the following equations:

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

$$\frac{\partial}{\partial t}(\rho \mathbf{v}) + \nabla \cdot \rho \mathbf{v}\mathbf{v} - \nabla \cdot (\eta\, \dot{\boldsymbol{\gamma}}) = -\nabla p + \mathbf{f}_\sigma \tag{2}$$

$$\frac{\partial}{\partial t}\left(\rho C_p T\right) + \nabla \cdot \left(\rho C_p T \mathbf{v}\right) - k\nabla^2 T = \eta \dot{\gamma}^2 + \dot{\alpha}\Delta H \tag{3}$$

Where $\dot{\boldsymbol{\gamma}}$, η, $\mathbf{f}_\sigma$, $\dot{\gamma}$, $\dot{\alpha}$,denote the rate of strain tensor, the viscosity, surface force, the shear rate, and the conversion rate respectively.

Several assumptions are made to simplify this problem :

(1) Assume working fluid is incompressible.
(2) Assume working fluid is pure viscous fluid, no polymer elastic effect is considered.
(3) The filling process is non-isothermal. For the initial preheating temperature different between encapsulant and mold, the encapsulant would continuously released reaction heat during filling.
(4) Assume the material properties of encapsulant such as heat capacity C_P, reaction heat ΔH, heat conduction coefficient k, and surface tension coefficient are constant.
(5) Assume non-slip boundary condition is applying on cavity wall.

A volume fraction function f is introduced to track the evolution of the melt front. Where $f = 0$ is defined as the air phase, $f = 1$ as the melt phase and the melt front is located within control volume between 1 and 0. The advancement of f over time is described by the following transport equation:

$$\frac{\partial}{\partial t} f + \nabla \cdot f\mathbf{v} = 0 \tag{4}$$

HRIC (High Resolution Interface Capturing scheme) differencing method [3]is applied to avoid interface being blurred.

The surface tension force is described by CSF(Continuum Surface Force) model proposed by Brackbill[4]:

$$\mathbf{f}_\sigma = -\sigma\kappa\left(\nabla f\right) \tag{5}$$

Where σ is the coefficient of surface tension and κ is the curvature of free surface.

The rheology of the encapsulant is modeled as Castro-Macosko Model[5]:

$$\eta(\dot{\alpha}, T, \dot{\gamma}) = \frac{\eta_0(T)}{1 + \left(\frac{\eta_0(T)\dot{\gamma}}{\tau^*}\right)^{1-n}} \cdot \left(\frac{\alpha_g}{\alpha_g - \dot{\alpha}}\right)^{C_1 + C_2\dot{\alpha}} \tag{6}$$

$$\eta_0(T) = B\exp\left(\frac{T_b}{T}\right) \tag{7}$$

$$T_b = E_a / R \tag{8}$$

Where E_a is the active energy of viscous flow, R is the ideal gas constant, α_g n, B, τ^*, C_1, C_2 are material model parameters. This equation can predict the viscosity of the gel point value approaches infinity. And also can predict well for cross-linked thermosetting compound viscosity. Since the encapsulant is a thermosetting material, we adopt combined kinetic model to describe curing behavior:

$$\dot{\alpha} = \frac{d\alpha}{dt} = (k_1 + k_2\alpha^m)\cdot(1-\alpha)^n \quad (9)$$

$$k_1 = A_1 \exp(-E_1/T) \quad (10)$$

$$k_2 = A_2 \exp(-E_2/T) \quad (11)$$

Where α denotes degree of cure, m and n represent the constants for the reaction order, k_1 and k_2 are the rate parameters described by Arrhenius temperature with A_1 and A_2 as pre-exponential factors, E_1 and E_2 are activation energy.

The collocated cell-centered finite volume method proposed by Chang and Yang [6] is modified to apply in this work. Base on a SIMPLE-like iteration procedure, the method has improved numerical stability and robust convergence. Pressure, velocity, temperature and volume fraction fields are segregated in the solver so that the efficiency can be achieved even for 3D calculation. This model will cooperate with CSF model to catch more accurate surface effect in capillary action.

RESULTS AND DISCUSSIONS

Since the capillary flow type flip chip package is driven by the surface tension force, the validation test of surface tension is extremely important. In this section, we first test the accuracy of our simulation tool and demonstrate the simulation results in multi-bump underfill configurations.

In this first test, the initial conditions given a side length of 3.75 cm square of ethanol droplet. Because the role of surface tension, the liquid surface tension tend to minimize surface area naturally. The droplet shape gradually from the initial square into a circle. From the result of Fig. 1, because the surface tension of the surface caused by the considerable power, the resulting droplets will have periodic vibration of the surface. The following case is to test for wall adhesion of the boundary conditions. Here given a 10x10 cm^2 of the tank where is full of 4 cm depth of water. The influence of gravity would not be considered here and the simulation assumed that the contact angle is 5 degrees, Due to the effect of surface tension, the water would form a concave surface eventually as Fig. 2. Both of the simulation results are consistent with reference [4] quite well.

While assuming the liquid viscosity, surface tension coefficient and the contact angle are constant, then we could derive the propagation of the underfill front to be given by:

$$t_{fill,L} = \frac{3\mu}{h\gamma\cos\theta}L^2 \quad (12)$$

where μ is viscosity, h is the gap size, γ is surface tension coefficient, and θ is contact angle. The computational model for this validation case and data is the same as [7]. From Fig. 3, we could see that in the capillary type underfilling process, the propagation velocity of the front decreased continuously as time progressed. So the general use of capillary -type chip package size would be limited. Too large chip size will make the filling time significantly elongated and no more cost-effective.

On the basis of above methods, the geometry of the chip would be studied as Fig. 5. The chip size is 7 mm $\times$ 7 mm , where the gap size is 0.7 mm. To reduce the total element number and analysis CPU time, there are only few solders bumps in the current chip and the shape of solder bumps is simplified as a cylinder with the radius of 0.08 mm. The distance between the centers of adjacent solder bumps is 0.25 mm. The encapsulant material properties is shown as Fig. 4. In this case, we set the contact angle as 10° and the coefficient of surface tension as 0.04 N/m.

In practical operations, we can adjust the injector moving velocity to change the dispensing rate. The moving speed for an injector of 5 cm/sec is simulated with time throughout the cavity in Fig. 6. From the conversion result in Fig. 7, we could know the conversion behaviors is following the filling pattern. Basically, the conversion is higher for the early filling area. And the pressure drop is even distribution in the simulation result. The negative pressure will happen in the void area where we could detect it from the filling pattern.

While adjusting the different moving speed of the injectors, the results show the same location of void formation as Fig. 8. This indicate the possible problem that may occur for this solder ball configuration. However, if we could have more information about dispenser such as volume of underfill per second, expansion volume of underfill and moving path by time, we think the simulation results of the dispensing process would be more realistic.

CONCLUSION

This study proposes a full 3D numerical approach to model the polymer melt filling behaviors in underfill encapsulation process. The finite volume method (FVM) is utilized to solve the 3D governing equations of flow and heat transfer. The melt-air interfaces are tracked through the algebraic volume-tracking method. The results illustrate the potential practice of an effective 3D approach tool for further process simulation and mold design for fine pitch underfill encapsulation. The simulation tool provides a promising simulation solution for the microchip encapsulation process. In the future work, the numerical results would be confirmed by comparing with more available experimental data to close to the real process.

REFERENCES

[1] “Amkor Press Releases”, http://www.amkor.com/go/about-us/press-releases

[2] Banijamali, B., Mohammed I., Savalia P., “Reliability of fine-pitch flip-chip packages”, Electronic Components and Technology Conference, ECTC 2009. 59th, 2009.

[3] Muzaferija S., Peric M., Sames P., Schelin T., “A two-fluid Navier-Stokes solver to simulate water entry”, Proc. Twenty-Second Symposium on Naval Hydrodynamics, 1998.

[4] J.U. Brackbill, D.B. Kothe, and C. Zemach, “A Continuum Method for Modeling Surface Tension”, Journal of Computational Physics, vol. 100, p. 335, 1991.

[5] J. M. Castro, C.W. Macosko and S. J. Perry, ”Viscosity Change during Urethane Polymerization with Phase Separation”, Polym. Comm., Vol. 25, 82, 1984.

[6] W. H. Yang and R. Y. Chang, “Numerical Simulation of Mold Fill in Injection Molding Using A Three-Dimensional Finite Volume Approach”, International Journal for Numerical Methods in Fluids, vol. 37, p. 125, 2001.

[7] Yang H., Bayyuk, S., Krishnan A., Przekwas A., Nguyen L., Fine P., ”Computational simulation of underfill encapsulation of flip-chip ICs. I. Flow modeling and surface-tension effects”, Electronic Components & Technology Conference, 48th IEEE, 1998.

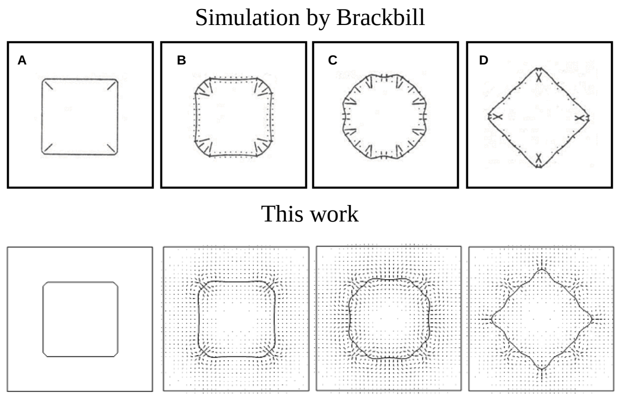

FIGURE 1. Shape revolutions of a ethanol droplet with time (A) 0.0, (B) 0.05, (C) 0.10, (D) 0.20 sec

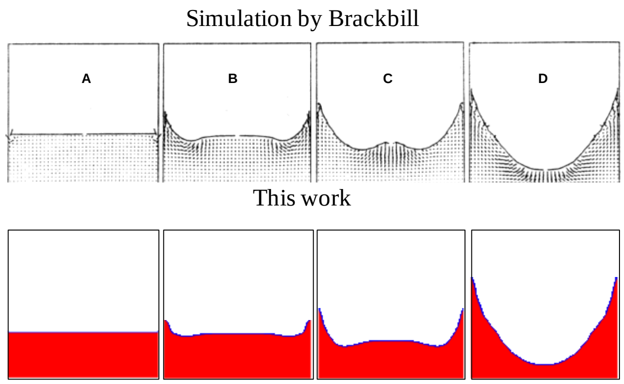

FIGURE 2. Shape revolutions of 5 degrees contact angle for water with time (A) 0.0, (B) 0.2, (C) 0.4, (D) 0.6 sec

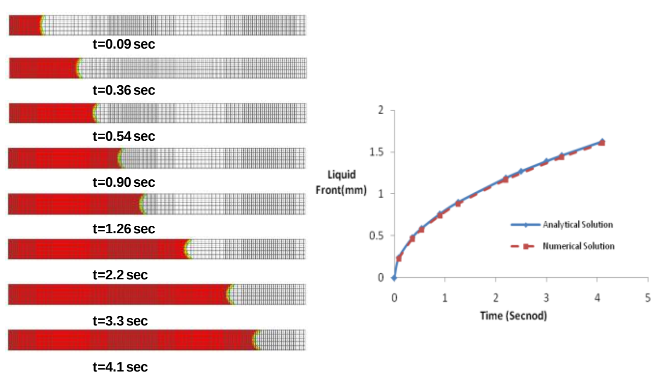

FIGURE 3. Liquid-Gas front propagation in a channel due to surface tension

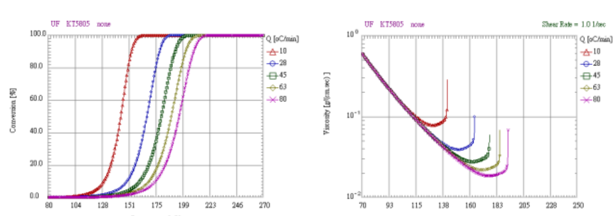

FIGURE 4. Material properties of viscosity and curing kinetics

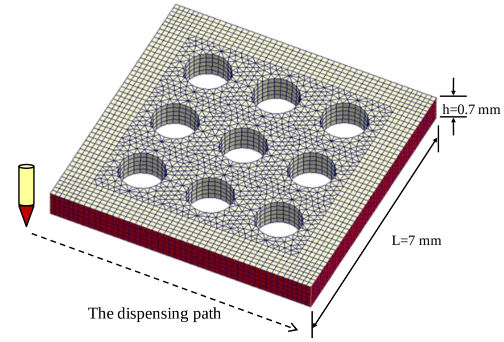

FIGURE 5. Configuration for a multi-bump underfill flow

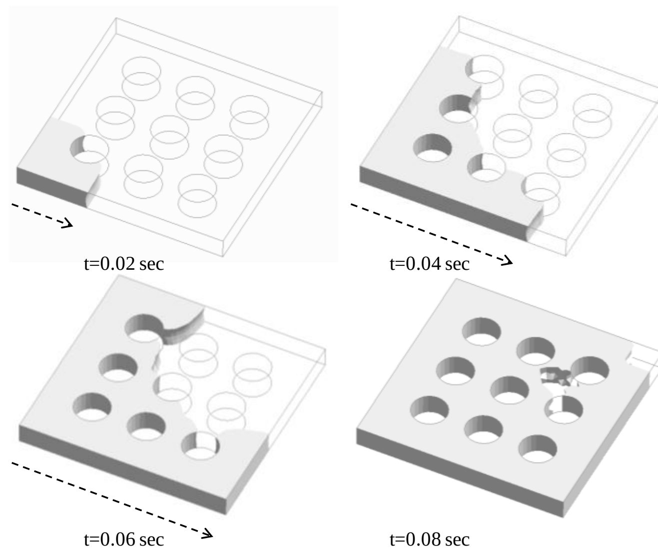

FIGURE 6. Front propagation for a testing underfill problem

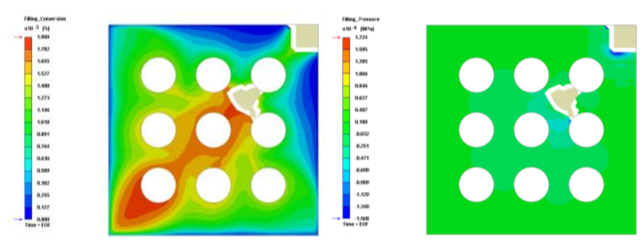

FIGURE 7. The conversion(left) and pressure(right) distribution for moving speed of V=5 cm/sec

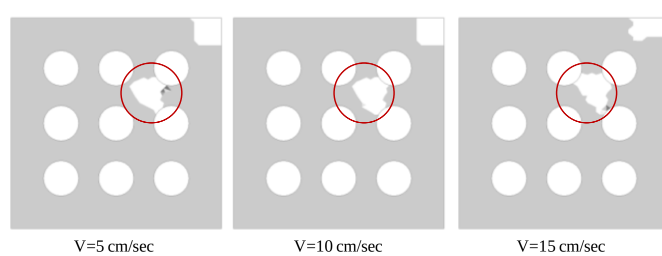

FIGURE 8. Possible void location for different moving speed of the injector