Moldflow simulation of an exposed pad leaded package

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Abstract
A study has been conducted for epoxy mold compound filling for a 48 lead exposed pad package. The leadframe design contains a small gap feature where it is critical to evaluate void estimates. A modeling method is being discussed to accurately predict the flow front behavior and make void percentage estimates. With improved design, void percentage significantly goes down as predicted by models. The paper contains detailed methodology for creation of CAD model with standard leadframe drawing and final analysis using a defined gate area. Fill time contours shows significant improvement comparing two designs with 35 μm and 65 μm gap feature.

Key words
Moldflow simulation, leaded package EMC filling, void estimates

I. Introduction
An electronic package goes under molding process which provides a secure housing and protection for the silicon chip from external contaminants or moisture in addition to providing the mechanical support. Transfer molding process is the most widely used technique to encapsulate the package where an epoxy mold compound in form of pellet is transferred under high pressure from pot to cavity through a runner and gate system. The mold chase is typically maintained at melting temperature of the mold compound which initiates the flow inside the mold cavity and further reaction kinetics of the compound initiates the curing process. The transfer molding process has been used for encapsulating different kind of packages such as mold array package (MAP) [1] and ball grid array packages (BGA) [2]. The fluid flow behavior for a mold compound depends on material characteristics as well as the process control parameters. For accurate prediction of fluid flow front, void estimates and wire sweep through numerical simulation, it is important to know mold material properties, accurate package geometry and process control settings. Epoxy mold compound properties are obtained through rheological experiments and both reactive viscosity model and reaction kinetics model are required in order to run a simulation.

In this paper, a simulation study is presented for an exposed pad leaded package with regards to fluid flow front behavior and void estimate prediction. The detailed steps are discussed right from leadframe design to 3D CAD model creation to mold flow simulation. The simulation has been performed using Autodesk Moldflow which supports study for microchip encapsulation; along with several other modeling tools such as C-MOLD , Moldex 3-D , etc. and has been discussed in literature [3-5]. Fill time contours are shown at intermediate steps which gives an accurate idea of melt front advancement and flow imbalance. Further a comparison of pressure contours is being shown for two different gap features (35 and 65 μm) of the package showing higher probability of void creation for smaller gap geometries.

II. A Brief Review
One of the earliest works for moldflow simulation for an electronic package was done by Nguyen [6]. The study uses an experimental mold considering multiple cavities where the mold can be modified for both temperature and pressure measurements. Effect of transfer speed, initial resin conversions, mold temperature, preheat temperature, velocity/pressure switch over and thermal conductivity is being discussed for different type of cavities. Further limitation of the simulation program is discussed as the tool was originally developed for injection molding of reactive materials such as polyurethanes and was later extended for IC encapsulations. The limitation include proper venting,

non uniform platen temperatures, perform conditions, runner/gate true geometry, flow balancing, viscoelastic effects, complex three dimensional flow, wire sweep and void modeling. The paper also discusses more challenges in form of getting accurate material properties which is an important prerequisite for accurate parametric model for material's rheokinetics and predicting viscosity of a curing epoxy at any point in its time-temperature thermal history. The major mold defects such as wire sweep and voiding still requires phenomenological models in order to be addressed.

Chai et al. [7] discusses the modeling technologies developed to analyze the mold flow during package encapsulation. Cavity thickness is shown to be the most important parameter which affects the mold flow behavior for leaded packages. Large thickness difference in top and bottom cavity can lead to unbalanced flow which can cause air traps and die pad tilt. The paper shows several case studies related to short-shot samples of 54 lead TSOP, TFTBGA, 208 lead LQFP and 256 lead QFP package where mold compound behavior is influenced by cavity thickness, bonding wire density, leadframe opening size and surface roughness. With the use of moldflow simulation, it was feasible to have a lead frame design direction, estimate correct die thickness, heat spreader thickness and suggest better heat spreader design.

Lee et al. [8] performed a full three dimensional rheokinetic simulation for a three die stacked structure with 4x4 mold array. Four different gate types were investigated where center gate showed more severe voids but corner gates showed relatively lesser voids. Simulation results indicated increased velocity, shear stress and mold pressure near gate inlet and final filling zone; when gate was located at the corner. Wire sweep prediction requires multiple steps and several tools are required in order to determine the final sweeping results.

Yen et al. [9] has shown the applicability of mold flow software for molded underfill flip chip package with different stand-off heights. It is being shown that molded underfill structure with a maximum standoff height of 50 µm shows lower air void risk as mold compound can easily flow under the die region. The paper demonstrates the successful use of CAE technology for flow modeling of the transfer molding process for molded underfill packages.

Li et al. [10] has analyzed moldflow simulation for a MEMS fingerprint sensor package and have studied the distribution of the potential void in the package. Influence of location and different gate size is also being studied. It is being shown that dual gate configuration leads to much better melt flow balance compared to single gate configuration. Gate design does play an important role in enhancing the flow balance and reducing the voiding problem.

Khor et al. [11] has provided an extensive review on fluid structure interaction highlighting the modeling challenges related to different flow induced phenomena such as wire sweep, paddle shift, lead frame deformation and through-silicon via deformation. Wire sweep simulation modeling poses several challenges such as mesh element control, wire bond shape complexity and including high wire density. Increase in wire density leads to increase in number of mesh elements which increases CPU usage for analysis.

III. 3-D Mold Flow Analysis

A. Governing Equations

The governing equations for melt flow advancement for an epoxy mold compound inside a mold cavity can be mathematically described in form of basic conservation laws as shown in (1-3). Theoretically, the process is transient, reactive and three dimensional for a moving flow front.

For a constant density, incompressible flow; continuity equation can be described as

$$\frac{\partial \rho}{\partial t} + \nabla \bullet (\rho \vec{u}) = 0; \qquad \nabla \bullet (\rho \vec{u}) = 0 \tag{1}$$

Conservation of mass is essentially the traditional form of Navier- Stokes equation as shown below:

$$\frac{\partial}{\partial t}\left(\rho \vec{u}\right) + \nabla \bullet (\rho \vec{u}\vec{u}) = -\nabla p + \nabla \bullet \left(\eta \dot{\gamma}\right) + \rho \vec{g} \tag{2}$$

Conservation of energy can be described in form of:

$$\rho C_p \left(\frac{\partial T}{\partial t} + \vec{u} \bullet \nabla T\right) = \nabla\left(k \nabla T\right) + \left(\eta \dot{\gamma} + \dot{\alpha}\,\Delta H\right) \tag{3}$$

where u is the three dimensional velocity vector for all three directions (x, y, z) , ρ is the density, p is the pressure, η is the viscosity, $\dot{\gamma}$ is shear rate, g is gravity vector, C_p is the specific heat capacity, T is the temperature , k is thermal conductivity, $\dot{\alpha}$ is conversion rate and ΔH is the exothermic heat of polymerization.

B. Rheokinetic behavior of epoxy mold compound

Epoxy mold compound are typically characterized as thermoset polymers with numerous additives and fillers. For this study, rheokinetic properties are acquired from supplier and will be shown later in the section.

For transfer molding process, flow and heat transfer is dynamically coupled with curing reaction. Viscosity is not only primarily affected by shear rate and temperature but is also a strong function of degree of conversion of the mold compound. Hence, rheology of the molding compound is of utmost importance for flow modeling and heat transfer behavior inside the mold cavity.

Viscosity model used for the study is in form of Cross-Macokso model [12] which was developed by Castro and Macosko to describe polymerization behavior and is shown in (4).

$$\eta = \frac{\eta_0}{1+\left(\frac{\eta_0 \dot{\gamma}}{\tau^*}\right)^{1-n}} \left(\frac{\alpha_g}{\alpha_g - \alpha}\right)^{c_1 + c_2 \alpha} \qquad (4)$$

$$\eta_0 = Be^{\frac{T_b}{T}}$$

where η is the viscosity, η_0 is zero shear viscosity, $\dot{\gamma}$ is shear rate, T is the temperature field and α is the degree of cure (0-1). n, T_b, τ^*, B, c_1, c_2 and α_g are data fitted coefficients shown in Table 1.

Table 1: Numerical Parameters for Cross-Macosko Model

Fitting Parameters	*Unit*	*Value*
n	-	6.635e-01
τ^*	Pa	1.0e-04
B	Pa-s	2.393e-01
T_b	K	5.248e+03
c_1	-	3.937e+0
c_2	-	6.045e+0
α_g	-	8.476e-01

The curing kinetics parameters are defined using Kamal model which is integrated with Cross-Macosko model. The rate of degree of conversion can be predicted by (5).

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

$$k_1 = A_1 \exp\left(-\frac{E_1}{T}\right) \qquad (5)$$

$$k_2 = A_2 \exp\left(-\frac{E_2}{T}\right)$$

where α is the degree of conversion, k1 and k2 rate parameters based on Arrhenius temperature dependency, m and n are reaction orders, A_1 and A_2 are Arrhenius pre-exponential factors, E_1 and E_2 are activation energies and T is the absolute temperature. Fitting parameters for the mold compound used in study is provided in Table 2.

Table 2: Numerical Parameters for Kamal Model

Fitting Parameters	*Unit*	*Value*
m	-	4.842e-01
n	-	1.178e+00
A_1	1/s	1.000e-01
A_2	1/s	6.295e+06
E_1	K	2.000e+04
E_2	K	8.471e+03

C. Package Geometrical Model

Before performing simulation, package 3-D CAD model has being prepared using leadframe geometries and other components such as die, die attach and the epoxy mold compound. Lead frame geometries are typically generated in form of drawing files (.dwg) which is a two dimensional information. The geometry needs to be cleaned by removing the annotations, texts, symbols and peripheral lead geometries for extrusion purpose. The peripheral lead geometries are excluded from the model as it is external to mold chase boundaries and not needed for filling analysis.

The closed contour for the 48 lead exposed pad geometry with a package size of $7x7mm^2$ is prepared using Autodesk AutoCAD and is shown in Figure 1. The extrusion process is done using ANSYS Design Modeler where the defined downset is provided to create a three dimensional lead structure. Next step is to do appropriate scaling and transformation to have correct dimensions during analysis. Die, die attach and mold volume is created to have the complete package structure. Bond wire geometries are not included in the model in order to avoid the meshing complexity. For mold flow analysis, it is desired to create a pure mold volume by negating all other volumes (such as die, die attach and leadframe). The negated mold volume is exported as (.step) file which is later used in Autodesk Moldflow for filling analysis and void estimates.

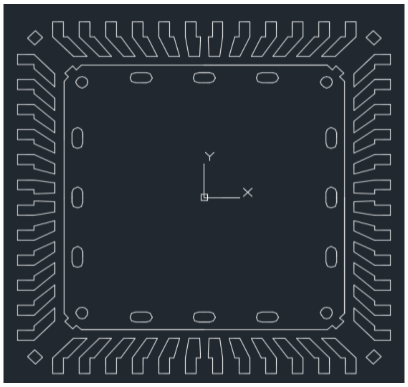

Figure 1: Closed contour leadframe geometry before extrusion

The leadframe design for this particular study also contains a finer gap feature which basically creates an annular ring feature on the peripheral flag area to facilitate the down bonding. The gap is basically created by deforming the metal at the flag edge. Schematic of the package cross section is shown in Figure 2.

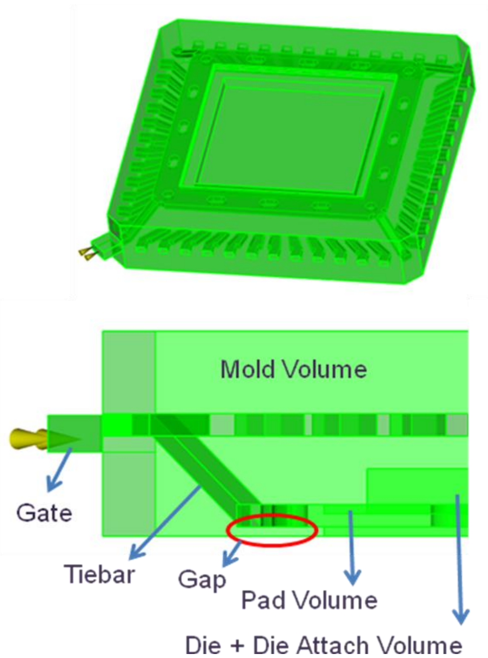

Figure 2: 3-D Mold Volume with a cross section

The important geometrical parameters for the package and gate are summarized in *Table 3*.

Tetrahedral mesh is considered in the model where number of tetrahedras is 905844 and connected nodes are 163306 for 65 µm gap geometry. Mesh independent study was carried out in order to achieve the optimum number of nodes which accurately captures all the finer details of the geometry without affecting the accuracy of the models.

Table 3: Package dimensions considered for model

Component	*Unit*	*Size*
Die Area	mm^2	3.4x3.4
Flag Area	mm^2	5.3x5.3
Mold Area	mm^2	7x7
Mold Thickness	mm	1.4
Lead frame I/O	-	48
Lead frame downset	mm	0.684
Gap size/height	µm	35 & 65
Gap length	mm	0.56
Gate area	mm^2	0.25x0.49

D. Results

The fill time contours at different time intervals for the studied mold compound is shown in Figure 3. The filling initiates for the gate entry region and flow progresses towards vent located in the diagonal corner of the package.

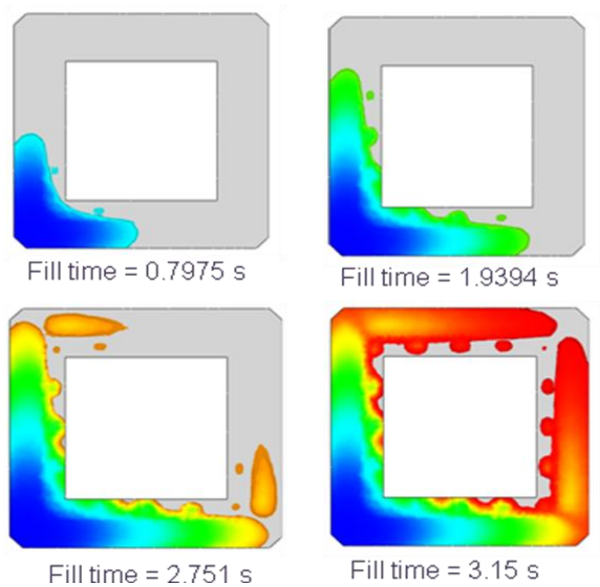

Figure 3: Fill time contours for 65 µm gap design

The cross section is exactly located in half way of the gap height to accurately capture the flow behavior under the narrow region. It can be observed that there are multiple flow fronts which meet at the later stage of the flow and can lead to potential air traps. The computational tool does provide a potential air trap contour but the best prediction can be made through the fill time profile. At fill time of 2.751s, fill dots appearing at top and right quadrant are the fill patterns caused due to presence of mold lock hole feature on the leadframe. A more refined contour plot is shown in Figure 4. The real objective of the mold lock holes is to provide better bulk volume to avoid any delamination; but in this case, it participates in filling the gap region as well. At the end of the fill (3.15 s), it is seen that major flow front moves towards the venting location but there exists a region surrounding mold lock holes which is still unfilled. It is expected that packing phase of the flow will reduce the size of potential voids but it cannot be completely eliminated.

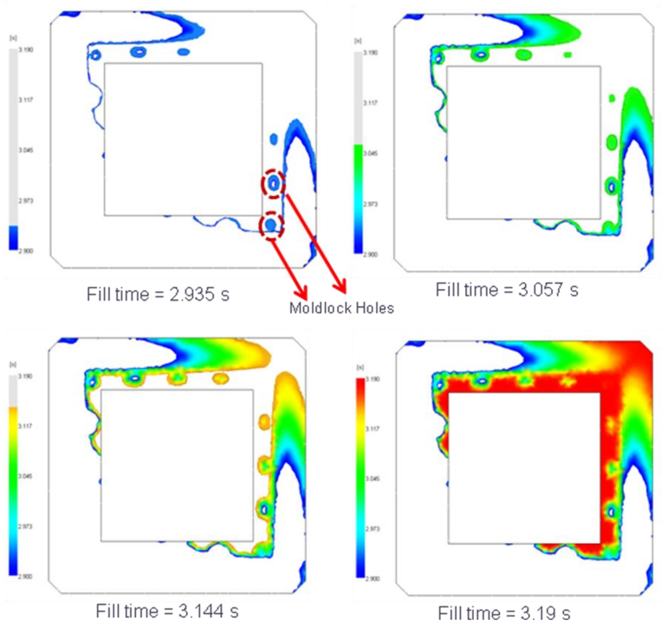

Figure 4: Refined flow scale for 65 µm design with better flow distribution

Similar study was done for 35 µm design and same flow distribution is observed with more pronounced potential air trap locations as shown in Figure 5. At fill time of 3.183s, flow front is observed to be at the corner venting location but gap region is still majorly unfilled. A better way to understand the size of potential air traps is through pressure contours during velocity to pressure switchover point as shown in Figure 6. The pressure tends to be zero under the gap region which basically suggests that flow cannot progress further into the gap zone.

It can be seen that the unfilled area in case of 35 µm design is significantly higher (roughly 33%) than 65 µm design case. This suggest that 35 µm design has much higher potential for creating air traps compared to 65 µm feature.

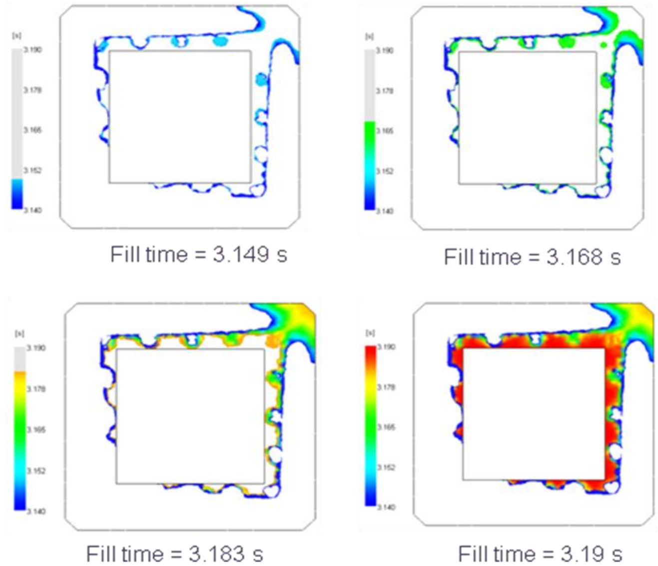

Figure 5: Refined flow scale for 35 µm design

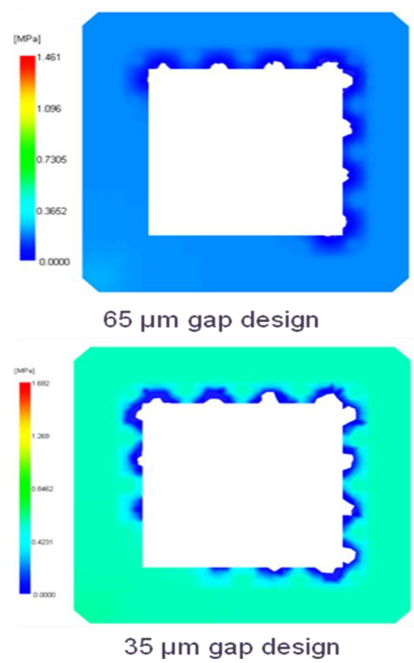

Figure 6: Pressure contours at the end of the fill

Based on the studies, it is desired to have much larger gap height in order to reduce the pressure drop under the gap region. But it would be limited by leadframe thickness, which is 0.127 mm in this case. To have better filling, more design options is being explored in terms of increasing the mold lock hole size and reducing the gap length.

IV. Conclusions

A study has been conducted to understand the flow behavior for an exposed pad leaded package using state of art simulation tool. The existing tools can solve the dynamical coupling of flow, heat transfer and curing reaction of an epoxy mold compound for the package. The study was more focused on understanding the influence of gap feature and its affect on creating potential air traps. It was observed that for much smaller height of 35 µm, the air trap contours are much more pronounced compared to 65 µm gap design. It is required to have larger gap height in order to reduce the pressure drop further. Few other design options such as reducing gap length and more number of mold lock holes feature would be explored in future studies.

References

[1] Schreier-Alt T, Rehme F, Ansorge F, Reichi H, *Simulation and experimental analysis of large area substrate overmolding with epoxy molding compounds*, Microelectronics Reliability 2011;51:668–75.

[2] Bae DH, Lee MC, Lee ES, Yun HC, Lim JC, Kim IB, *Simulation of encapsulation process for BGA type semi-conducting microchip*, Journal of Industrial & Engineering Chemistry 2003;9(2):188–92.

[3] Chang RY, Yang WH, Hwang SJ, Su F, *Three-dimensional modeling of mold filling in microelectronics encapsulation process*, IEEE Transaction of Component Package Technology 2004; 27(1):200–9.

[4] Wang H, Zhou H, Zhang Y, Li D, *Stabilized filling simulation of microchip encapsulation process,* Microelectronics Engineering 2010;87(12):2602–9.

[5] Wang H, Zhou H, Zhang Y, Li D, Xu K, *Three-dimensional simulation of underfill process in flip chip encapsulation*, Computational Fluids 2011;44(1):187–201

[6] Nguyen LT, *Reactive flow simulation in transfer molding of IC packages*, 1–4 June, Orlando, FL, 0569–5503/93/0000-0375 IEEE, 1993. p. 375–90.

[7] Chai K, Liu V, Wang Y.P, Her T.D, *The Application of Mold Flow Simulation in Electronic Package*, International Symposium on Electronics Materials and Packaging, 2000, pp. 330-334

[8] Lee M W, Khim J Y, Yoo M, Chung J, Lee C H, *Rheological Characterization and Full 3D Mold Flow Simulation in Multi-Die Stack CSP of Chip Array Packaging,* 56th Proceedings of Electronic Components and Technology Conference, 2006

[9] Yen F, Hung L, Kao N, Jiang D S, *Moldflow Simulation Study on void risk prediction for FCCSP with molded under fill technology,* 16th Electronics Packaging Technology Conference, IEEE, 3-5 Dec 2014, pp 817-821

[10] Li G, Yang D, Li R, Cai M, Li C, Wang L, *Mold flow analysis of molding process for a MEMS fingerprint sensor package*, 15th International Conference on Electronic Packaging Technology (ICEPT), 12-15 Aug 2014, pp 1534-1538

[11] Khor C Y, Abdullah M Z, Lau C S, Azid I, *Recent fluid-structure interaction modeling challenges in IC encapsulation – A review*, Microelectronics Reliability, Aug 2014, 54(8), pp 1511-1526

[12] Castro JM, Macosko CW, *Kinetics and rheology of typical polyurethane reaction injection molding systems*, SPE Tech Pap 1980; 26 :434–8.