Thermomechanical Effects of the Packaging Molding Process on the Chip in Integrated Circuits

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1.Abstract

Usually, in integrated circuits, the chip is brazed on leadframe and then, a (black) polymer resin is molded around to create the packaging. On the first hand, the molding process at high temperatures will induce thermomechanical stress on the chip. As the leadframe, the chip and the braze have all different thermoelastic properties, these stress can be critical for the chip connections [1]. On the other hand, we can also consider, during the injection of the hot fluidic polymer, the mechanical interaction between the fluid and the chip. This can also induce deformation of the chip on the leadframe.

To illustrate those eventual problems, we designed simulated studies with the COMSOL Multiphysics tools, using industrial cases from ST Microelectronics molding process and integrated circuits. This paper will describe the mechanical consequences of the molding process for the packaging of integrated circuits, which are critical for their reliability [2].

2. COMSOL study steps and governing equations

Obviously, the first step of our study is to load the model from CAD to COMSOL. The model is composed of three major parts: the leadframe in copper, the die in silicon and the pack in a specific polymer (fig. 1)

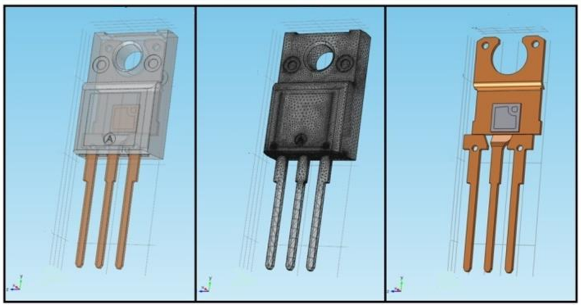

Figure 1 : View of the full system including leadframe die and the pack (left), the system meshed (mid.), and without the pack (right)

Then, we decided to split the study in two parts, first a thermoelasticity analysis at the molding temperature and then the impact of the molded fluidic polymer coming in the system.

To perform the molding process, the system (without the polymer, fig. 1c) is placed in the pre-heated mould close to the curing temperature of this resin we will introduce. The insertion of the polymer will be followed by a post mold cure that should be maintained for few hours at that same temperature [3]. As our industrial case, most of the polymer used to manufacture, the die packaging have a curing around T_{curing}=180°C [3].

So the first step of study, consisting in placing the system in the preheated mould, we will consider only the thermoelasticity without the fluidic interaction, we will use as simulation conditions a stationary study of the thermal stress and displacement at T_{melt}. We have to consider the energy (1) and forces balance (2) [4] available in the Comsol's Thermoelasticity node:

$$\rho_0 C_p \frac{\partial T}{\partial t} = \nabla(K\nabla T) + Q - T_{melt}\left(\frac{\partial \varepsilon}{\partial t}\right) \qquad (1)$$

$$\rho \frac{\partial^2 u}{\partial t^2} - \nabla\sigma = F.v \qquad (2)$$

The Fluid-structure Interaction node is used to study the second part of our problem due to the resin/die interaction during the injection stage. As initial values, we used the deformed mesh from the first equation, we can choose different polymer, we can also vary its injection speed and the pressure in the mould.

The COMSOL's node will consider the Navier Stokes' equation (3), conservation of matter (4) and forces balance (5) [5]:

$$\rho \frac{\partial u_{fluid}}{\partial t} + \rho(u_{fluid}.\nabla)u_{fluid} = \nabla\Big[-2pI + \mu(\nabla u_{fluid} + (\nabla u_{fluid})^T - \frac{2}{3}\mu(\nabla u_{fluid})I\Big] + F \qquad (3)$$

$$\frac{\partial \rho}{\partial t} + \nabla(\rho.u_{fluid}) = 0 \qquad (4)$$

$$\rho \frac{\partial^2 u_{solid}}{\partial t^2} - \nabla\sigma = F.v \qquad (5)$$

The last step of this study will be the cooling process of the system using the same node as the first but we had to add. Then the whole molding process will be simulated. The MEMS module is here really useful to investigate our study, because it gives us the ability to use an adapted Fluid

Structure Interaction and Thermal Stress physics [6].

3. Results

There are two main aspects to estimate in the problem : First, the maximum shear stress applied on the die volume, to explain if the die could break. Secondly, we will have to estimate the maximum deformation of the leadframe. To control this deformation, during the process, some pins (from 0 to 4) can be used to maintain the leadframe at its position, as it is described in the fig. 2. This pins are removed at the end of the injection step.

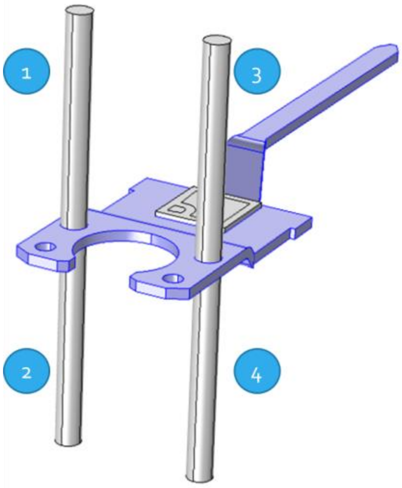

Figure 2 : View of the system with the pins

Step 1 : Pre-heating process

For this step, we first make the study varying the temperature T_{melt} using no pin :

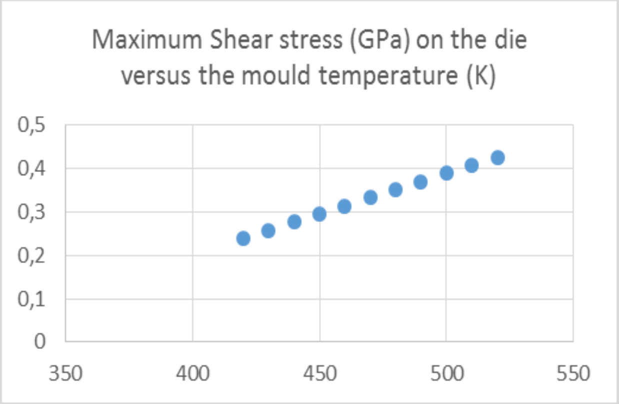

Figure 3 : Maximum shear stress simulated on the die volume versus the mould temperature.

In this fig.3 we can first first verify that with higher temperature we will observe more stress on the die, it will increase linearly with the temperature.

Now, we can make the comparison at a fixed T_{melt} between the solution from 0 to 4 pins see fig. 4 and fig. 5.

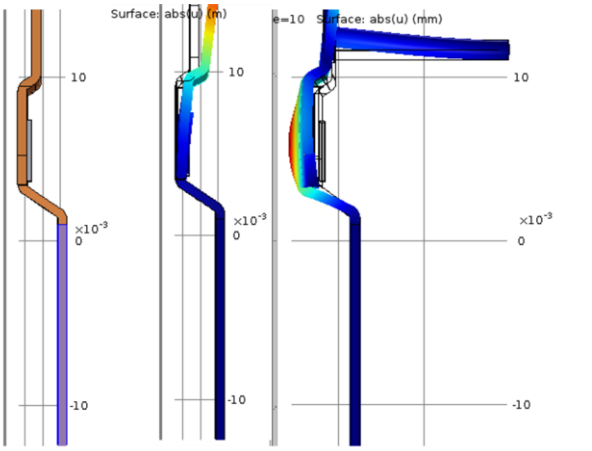

Figure 4 : Comparison of the deformation using one (right) or no pin (center) compared to the initial position (left)

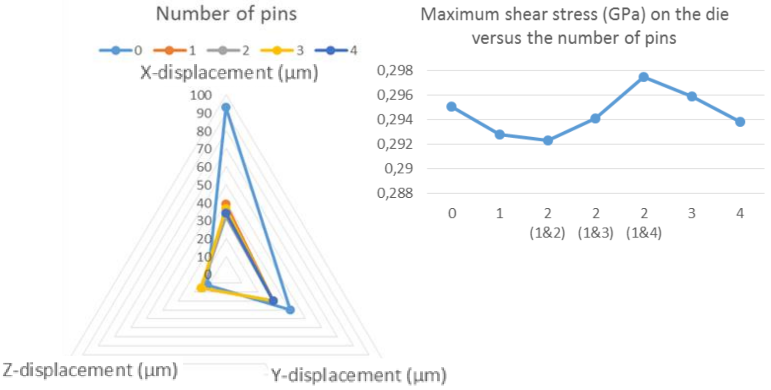

Figure 5 : Maximum deformation on the leadframe (left) and shear stress on the die (right) using different number pins

As we can see, concerning the shear stress applied on the die, we have quite the same results at about 300 MPa with or without pin. The deformation of the leadframe strongly drops with the first pin from 100 to about 30 µm in x-direction with pins.

Step 2 : Fluid-Structure Interaction

First we investigate the variation of the polymer injection speed in this study :

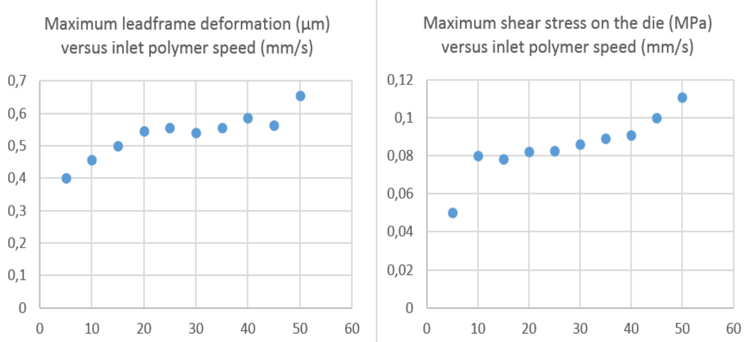

Figure 6 : Maximum deformation on the leadframe and shear stress on the die using different inlet speed of polymer

As we can see, the deformation and stress increase with the injection speed. But in comparison with the values from the first step, those values are not significative (about 100 time lower for the stress and 1000 for the deformation).

Step 3 : Cooling process

For the cooling process, we will measure the die stress and leadframe displacement, at ambient temperature T_{amb} considering the reference at T_{melt}.

The polymer has a glass transition temperature T_{glass} at which the thermal expansion coefficient switch from α_1 to α_2. To perform this change we will use the step function from Comsol with step function. For this step we simulated 3 different polymers with specific density, glass temperature transition, thermal expansion coefficients and Young modulus, which can be used by the industry, see fig.7.

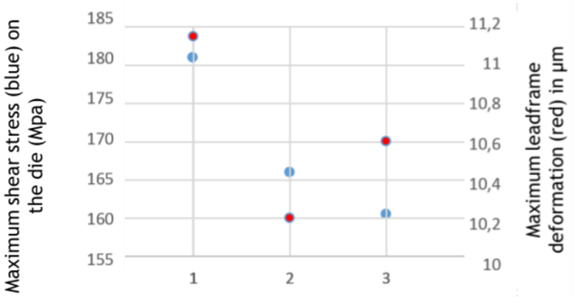

Figure 7 : Maximum deformation on the leadframe and shear stress on the die using during cooling step depending on the polymer used.

As we can see, we can observe a bigger shear stress on the die with the polymer 1 but with really low variations between the solutions.

4. Conclusion

This paper focuses on the prediction of the packaging process induced deformation and stress, that can be achieved under different process conditions. We first realized that the pins permits to decrease significantly from 100 to 30 µm. It can then confirm the utility of the pins and we can conclude only one pin should be enough to drop the leadframe deformation. We estimated on the die, a shear stress that can reach 300 MPa for the first step, 0.12 MPa during the injection and 180 MPa for the cooling step. This should not be enough to break the die, as the shear modulus of Silicon is close to 80 GPa. So the actual reliability problem that we can observe with some polymers could come from the solidification step that could be a subject for further studies.

5. Nomenclature

ρ_0 : Material's density (kg/m^3)
C_p : Material's thermic capacity (J/K)
Q : Quantity of heat supplied (J)
ε : Deformation
u and u_{solid} : Displacement field (m/s)
σ : Elastic stress (Pa)
F : Force (N)
v : Mesh (volume) element (m^{-3})
p : Pressure (Pa)
I : Identity matrix

6. References

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