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# COPPER LEADFRAME ANALYSIS USING THERMOMECHANICAL APPROACH

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## ABSTRACT

The use of copper-based structure leadframes in QFN is proven effective by three dimensional stacked-die. QFN packages in 3D Stacked-die structures take preference on the use of this leadframe design, a thick leadframe up to twice as thick as their leads thickness. Reducing the copper thickness is understood to present various thermal and reliability failure mode and mechanisms, such as die cracking, but apparently no in-depth study has been pursued to determine the thin leadframe is capable of achieving the defined. The drive towered die-free package cost (DFPC) has led the authors to assess and pursue the use of a thin leadframe in 3D stacked-die, with QFN – to reduce on the leadframe costs. The work presents an excellent basis for the qualification of a thin, and demonstrates the thermal and reliability performance of a thin version package. Finally, an extensive virtual thermal–mechanical prototyping was achieved to understand the physics during the assembly and thermal mechanical cycle load (TMCL) testing, QFN with a 3D stacked-die structure package leadframe, and a design rule was generated to prevent die crack.

## INTRODUCTION

The reliability of microelectronic packaging devices is a major concern in the electronic industries. Thermal-mechanical stress failure of the packaging materials is one of the leading causes of the microelectronic packaging component failure and reliability issues. The primary reason is that, with the periodical switching on and off in the circuit and the variety of environment temperature, the packaging component will experience thermal cycles. Because of the coefficient of thermal mismatch CTE of the constituent materials, the package undergoes periodic thermal stress and strain [1]. Epoxy Molding Compound (EMC) is widely used as encapsulating material and copper leadframe in electronic packaging, for example, in QFN packages, because of good thermal-mechanical properties and low cost. However, the leadframe and encapsulating materials are prone to thermo-mechanical failures, among which low-cycle fatigue is often prominent [2].

In the packaging and assembly processes, residual stresses will be introduced in the package. The residual stress can impose impact on the package reliability in many aspects. During the temperature cycling, thermal stress due to the mismatch of the coefficients of thermal expansion between dissimilar materials in the package may

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cause the initiation of crack and propagation, and finally it may result in the package failure [3]. With the decrease in electronic component volume and the increase in the density of input/output connects, the testing to the actual electronic component's thermal-mechanical performance becomes very difficult. The finite element analysis simulation becomes the important measure to analyze the thermal-mechanical reliability of electronic devices and assembly [4]. Though a great deal of research work on the solder fatigue has been published, not so much study on the thermo-mechanical fatigue of packaging polymers has been done [5, 6].

This paper uses finite element modelling to simulate the actual packaging process and temperature cycles of a QFN. Based on the simulation result, the paper focuses on the study of the process-induced residual stress and the thermal stress during thermal cycling which may cause thermal-mechanical stress on different leadframe thickness.

## LITERATURE BACKGROUND

### *Thermal loading*

In order to simplify the simulation process, the thermal loading history only includes cooling down from the curing process, reflow soldering process and three temperature cycles. Table 1 show the temperature profile used in the entire simulation (JEDEC 2004) [7]. The distribution of this profile is illustrated in Figure 1.

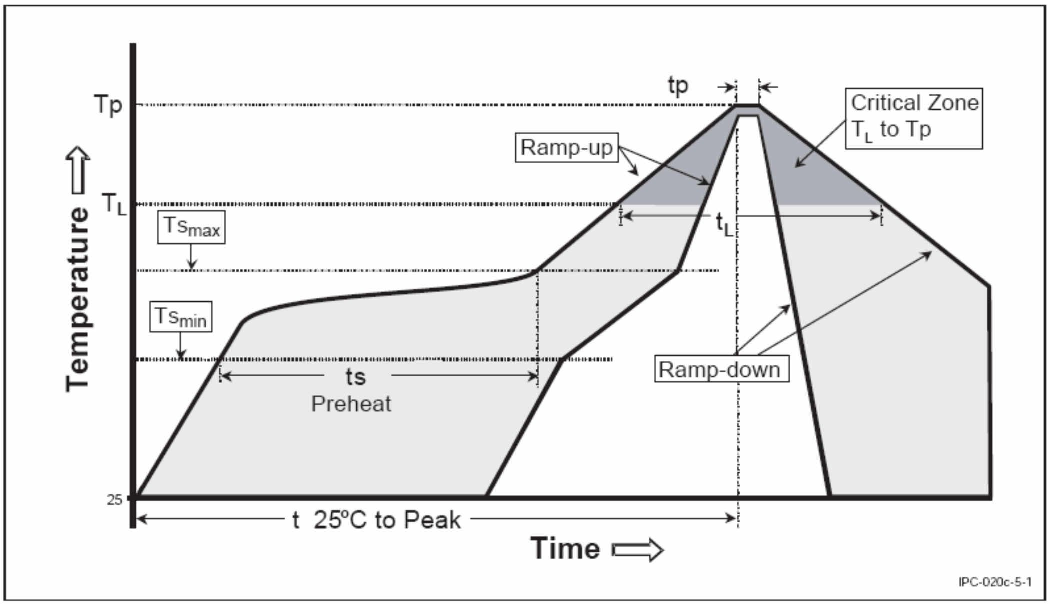

Figure 1: Classification Reflow Profiles (JEDEC 2004).

Referring to Figure 1, the reflow is not sooner than 15 minutes and not longer than four hours after removal from the temperature/humidity chamber, subject the sample

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to three cycles of the appropriate reflow conditions as defined in Table 1 and Figure 1. If the timing between the removal from the temperature/humidity chamber and initial reflow cannot be met then the parts must be rebaked and resoaked according to bake mean the sample for 24 hours minimum at 125 +5/-0 °C. This step is intended to remove moisture from the package so that it will be ‘‘dry’’ and moisture soak mean place devices in a clean, dry, shallow container so that the package bodies do not touch or overlap each other. Submit each sample to the appropriate soak requirements. At all times parts for etch temperature should be handled using proper Electronic Static Discharge (ESD) procedures. The time between reflows shall be five minutes minimum and 60 minutes maximum (JEDEC 2004) [7].

Table 1: Process Reflow (JEDEC 2004).

| *Profile Feature* | *Pb-Free Assembly* |
|---|---|
| Average Ramp-Up Rate ($Ts_{max}$ *to* $T_p$) | 3° C/second max. |
| Preheat | |
| – Temperature Min ($Ts_{min}$) | 150 °C |
| – Temperature Max ($Ts_{max}$) | 200 °C |
| – Time ($ts_{min}$ to $ts_{max}$) | 60-180 seconds |
| Time maintained above: | |
| – Temperature ($T_L$) | 217 °C |
| – Time ($t_L$) | 60-150 seconds |
| Peak/Classification Temperature ($T_p$) | 260 +0 °C |
| Time within 5 °C of actual Peak Temperature ($t_p$) | 20-40 seconds |
| Ramp-Down Rate | 6 °C/second max. |
| Time 25 °C to Peak Temperature | 8 minutes max. |

## METHODOLOGY: FINITE ELEMENT MODELING (FEM)

### *Geometry and FEM mesh*

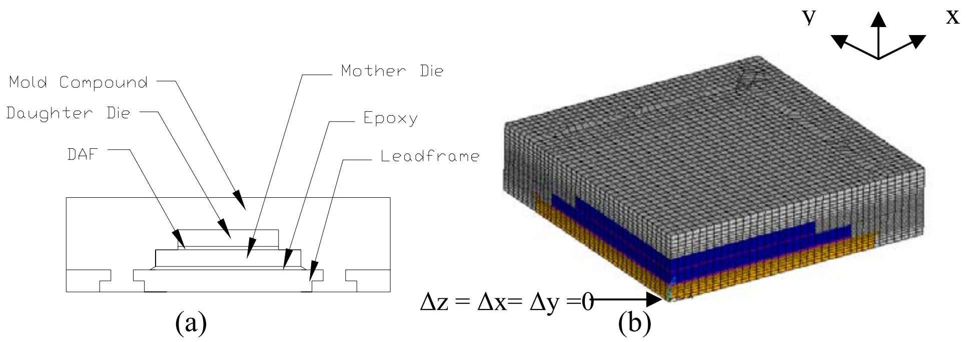

Figure 2: (a) A schematic diagram of QFN package for leadframe thickness of 0.20 mm, (b) FE mesh of QFN package.

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The QFN model was carried out by a fully matrix QFN 3D stacked-die package. In this paper, two models QFN with similar dimension were used. The schematic diagrams of QFN 3D stacked-die package are show in Figure 2(a) and 3(a). All packages are in the same size and thickness for which the package size is a 7x7mm and the package thickness is a 0.85mm. That size is selected it is because the package size 7x7mm gives high performance and more reliability of capability. The different of Figures 2 and 3 is thickness of leadframe and mold cap, Figure 2 show the leadframe thickness of 0.20mm and mold cap thickness of 0.65mm, Figure 3 shows the leadframe thickness of 0.15mm and the mold cap thickness of 0.70mm. All the material such as epoxy, mother die, die attach film (DAF) and daughter die is same material and dimension.

The modeling of the 3D plan strain is carried out by using ANSYS. Due to its symmetric structure, only one half of the structure is modelled. The FE mesh is presented in Figure 2(b) and 3(b). Following boundary conditions are used as the origin coordinates, $\Delta z = \Delta x = \Delta y = 0$ and nodes along the symmetric of axis uses the symmetric boundary conditions as show in Figure 2(b) and 3(b).

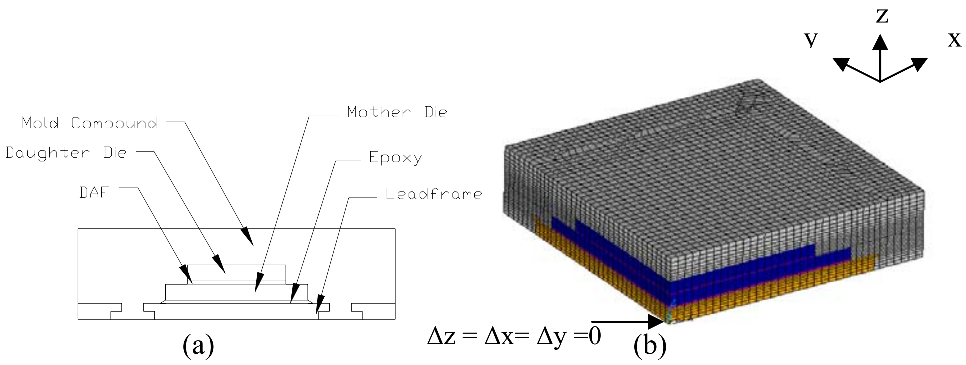

Figure 3: (a) A schematic diagram of QFN package for leadframe thickness of 0.15 mm, (b) FE mesh of QFN package.

*Materials properties and constitutive behaviour*

Table 2: Material Properties

| *Material* | *E (GPa)* | *Poisson's Ratio* | *G (GPa)* | *CTE (ppm/°C)* |
|---|---|---|---|---|
| Leadframe | 120.70 | 0.11 | 52.500 | 16.63 |
| Epoxy | 7.50 | 0.25 | 0.340 | 8.00 |
| Mother Die | 28.00 | 0.26 | 8.000 | 3.61 |
| DAF | 1.66 | 0.26 | 0.038 | 17.00 |
| Daughter Die | 28.00 | 0.26 | 8.000 | 3.61 |
| Mold Compound | 8.00 | 0.35 | 7.000 | 3.90 |

Table 2 shows the material properties. The Young's modulus allows the behaviour of a material under loading to be calculated. For instance, it can be used to predict the amount of material QFN package will extend under tension, or to predict the load at which a thin column will buckle under compression. Some calculations are also required such as shear modulus, density, or Poisson's ratio.

The behaviour of eutectic solder joints is modelled as temperature dependent with elastic-plastic and rate-dependent creep. According to previous researcher [4], the temperature dependent of the Young's modulus ($E$) is mathematically given for the following equation:

$$E(T) = 35366 - 151T \qquad (1)$$

where the temperature $T$ is in °$C$. The solder is assumed to be elastic - perfect plastic. The temperature dependent yield stress ($\sigma_y$) is described by the following equation [2 – 4]:

$$\sigma_y(T) = 49.2 - 0.097T \qquad (2)$$

the creep behaviour ($\dot{\varepsilon}_{cr}$) for a given material, different creep mechanisms may be operative at different temperatures and stress levels. To gain more insights into the time-dependent properties of the sample materials, it is desirable to obtain the relationship between the nanoindentation strain rates ($\varepsilon$) and the average indentation stress ($\sigma$) during the holding time. The creep behaviour mathematically defined as follow [2, 4, 8 – 9]:

$$\dot{\varepsilon}_{cr} = C_1\left(\frac{E}{T}\right).\left[\sinh\left(\frac{\alpha\sigma}{E}\right)\right]^n.e^{\frac{Q}{KT}} \qquad (3)$$

The EMC used in the QFN package is assumed as a time-temperature dependent viscoelastic material. The shear modulous is modelled with a Maxwell model ($G(t)$):

$$G(t) = G_\infty + \sum_{i=1}^{n} G_i.e^{-t/\tau_i} \qquad (4)$$

where $G_\infty$, is the equilibrium shear modulus, $\tau_i$ and $G_i$, are the relaxation time and stiffness coefficient corresponding to the term in the Maxwell model, respectively. The temperature effect is considered as thermorheologically simple material and by using the William-Landel-Ferry (WLF) equation:

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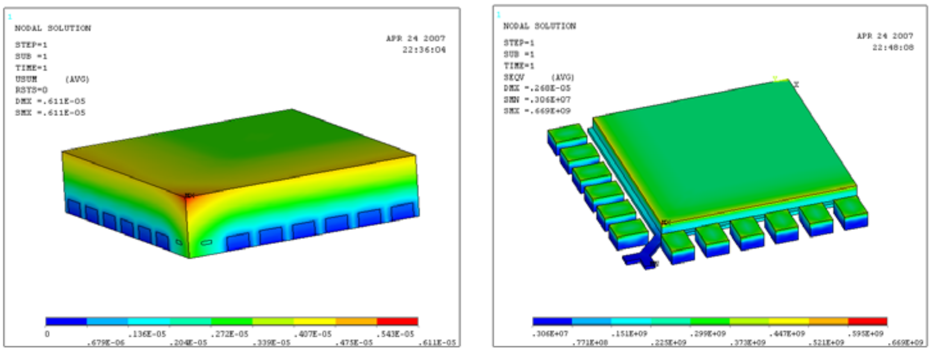
$$\log a_T = \frac{-C_1 \left(T - T_{ref}\right)}{C_2 + \left(T - T_{ref}\right)} \qquad (5)$$

in which, $T_{ref}$, is the reference temperature, $C_1$ and $C_2$, are the material constants. For this case, the Possion's ratio is assumed to be a constant value of 0.30. Based on the equations above, ANSYS software will utilize the equations to simulate the QFN package model.

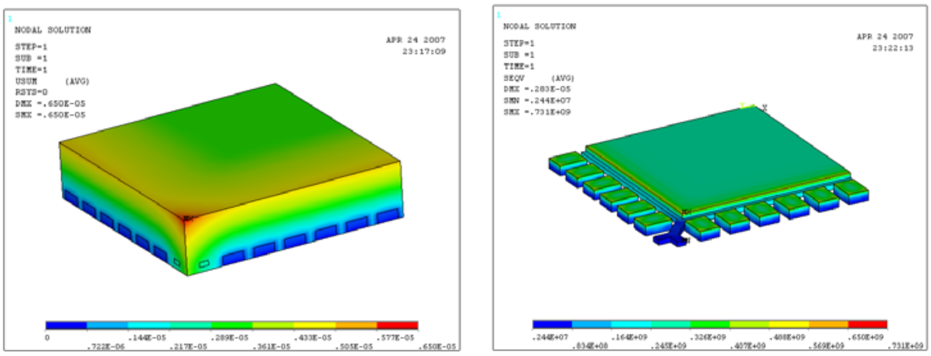
## RESULTS AND DISCUSSIONS

Figure 4 and 5 show the different stress distribution in the leadframe thickness between 0.20mm and 0.15mm at room temperature cooling from the curing process. Because of the higher curing temperature (260°C) and the mismatch of the coefficients of thermal expansion between dissimilar materials, the residual stress in leadframes is already induced at the initial stages of the thermal loading.



(a) (b)

Figure 4: FE modeling of the 0.20mm leadframe thickness: (a) displacement, (b) von-Mises-stress at leadframe.



(a) (b)

Figure 5: FE modeling of the 0.15mm leadframe thickness: (a) displacement, (b) von-Mises-stress at leadframe.

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Table 3 shows the numerical simulation result for displacement and von-Mises-stresses at leadframe of 0.20 mm and 0.15 mm. Stress distributed of component package such as mother die, daughter die, epoxy, DAF, leadframe and mold compound.

Two parts of stress distributed for QFN leadframe thickness of 0.20mm and 0.15mm is a displacement and von Mises stress. In Figure 4(a) and 5(a) show displacement for QFN using leadframe thickness of 0.20mm and 0.15mm is different. Simulation shows that QFN leadframe thickness of 0.15 and a mold cap of 0.70mm will give more displacement then QFN leadframe thickness of 0.20mm and mold cap 0.65mm, displacement on package just look at the displacement of mold compound and leadframe. Displacement between mold compound (0.70 mm) and mold cap (0.65 mm) is due to a higher poisson's ratio in the QFN package. The thickness and Poisson's Ratio of mold compound is a factor of more displacement for QFN leadframe thickness of 0.15mm. The situations of leadframe are similar then mold compound it is because leadframe is different thickness of that two QFN package. Different about two QFN displacements is 6% because of the rapid change of the temperature during the reflow process, the stresses are caused by the mismatch of the coefficients of thermal expansion between dissimilar materials. Figure 4(a) and 5(a) show both that at initial and terminal stages of the reflow process, the stress level is higher. Such high residual stress is remained at the end of the reflow process because of the solder joint restrict and indicates that the highest stress levels are always located on the center of the EMC**.** Therefore, the center surface is the potential failure site in EMC.

Table 3: QFN leadframe stresses.

| *component/ stress* | *Stress Distribution* | | | |
|---|---|---|---|---|
| | *0.20mm leadframe thickness* | | *0.15mm leadframe thickness* | |
| | *Displacement (m)* | *von Mises (Pa)* | *Displacement (m)* | *von Mises (Pa)* |
| Mother Die | 1.65E-06 | 3.59E+07 | 1.54E-06 | 3.66E+07 |
| Daughter Die | 1.65E-06 | 3.59E+07 | 1.54E-06 | 3.66E+07 |
| epoxy | 1.11E-06 | 1.01E+07 | 1.01E-06 | 1.07E+07 |
| DAF | 1.60E-06 | 7.84E+05 | 1.48E-06 | 7.99E+05 |
| leadframe | 2.68E-06 | 6.99E+08 | 2.83E-06 | 7.31E+08 |
| mold compound | 6.11E-06 | 1.50E+07 | 6.50E-06 | 1.35E+07 |

The von Mises stress, $\sigma_v$ is a scalar function of the components of the stress tensor that gives an appreciation of the overall 'magnitude' of the tensor. This allows the onset and amount of plastic deformation under triaxial loading to be predicted from the results of a simple uniaxial tensile test. It is most applicable to ductile materials. Plastic yield initiates when the Mises stress reaches the initial yield stress in uniaxial tension and, for hardening materials, will continue provided the Mises stress is equal to the current yield stress and tend to increase. Mises stress can then be used to

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predict failure by ductile tearing. Failures are unlikely to occur by crack propagation or fatigue, which depend on the maximum principal stress. In this case, for leadframe thickness 0.20mm, von Mises stress is 6.99E+08 Pa lower then von Mises stress for leadframe thickness 0.15mm is 7.31E+08 Pa, but for mold compound thickness 0.65mm is 1.50E+07Pa that higher then mold compound 0.70mm is 1.35E+07Pa. It is because the thickness of the material is a factor for this case. The high thickness gives the lower value of von Mises stress. However, the value of von Mises stress is acceptable value and it is because the value still lower than Young's modulus, *E,* which is listed in Table 2.

The leadframe thickness of 0.15 mm is a new design for industrial semiconductor, to fabricate this leadframe thickness are very expensive then fabricate leadframe thickness 0.20 mm. Simulation on two leadframe thickness prove that the reliability of two leadframe thickness is not big concern. This is why many manufacturers still prefer to produce leadframe with 0.20 mm thick.

## CONCLUSIONS

A study on the packaging process induced initial stress-state of a selected QFN package was presented in this paper. The assembly packages are considered to be elastic-plastic temperature dependent and rate dependent creep behavior. The viscoelastic behaviour of EMC during and after reflow process is simulated subsequently followed by temperature cycling simulations. From the simulation, it is shown that a thin leadframe increases a stress value of the package components. However, the increment of stress is approximately 0.02% difference between the stress performed by the with 0.2 mm leadframe thickness. The stress distribution obtained for the second leadframe with 0.15 mm thickness was still under the Young's modulus value. It is suggested that in order to make some adjustment either by material selection or the dimension of the package, for the material selection is select the coefficients of thermal expansion (CTE) material is not too high difference and it will be perform a lower and better stress value and the residual stresses are caused by the mismatch between dissimilar materials during the reflow soldering process. And at the end of the reflow the tensile stress at the center surface of EMC is at the highest level, the center surface can act as a possible failure site.

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