APPENDIXS

Structural Analysis of Lead Frame Design of Dual Row Quad Flat No Lead Package (QFN) Using ANSYS

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Abstract— **This study presents the mechanical characteristics on the stress of the Dual Row Quad Flat No Lead (DR-QFN) of a 44 lead DR-QFN package on the staggered lead frame design and 48 lead DR- QFN package on the inline lead frame design. The steady-state structural analysis for DR-QFN package with different lead frame design is performed using ANSYS software. Reducing the lead frame thickness is the other technique presented in this study. This is to analyze the stress behavior in the DR-QFN package. The 3D models used in this study were built using finite element method with SOLID 70 and MESH 200 element types. From the study, results show that thinner lead frame gives smaller value of stress. DR-QFN package with lead frame thickness of 0.15 mm has about 6% smaller value of stress compared to package with lead frame thickness of 0.20 mm. For lead frame configuration analysis, staggered and inline lead frame design, the staggered configuration has about 0.55% smaller value of stress compared to inline configuration.**

Keywords - QFN, dual row, design, leadframe, finite element method.

I. INTRODUCTION

The technology, especially mobile phones are becoming faster in term of speed processor as consumers nowadays are getting more particular in the size, cost and functionality of electronic gadgets. Quad flat no lead (QFN) is one of the fastest growing package types in the electronics industry. The QFN is the future generation technology for non-consumer electronic that is suitable with the concern of reliability and others [2]. As a low-cost solution for electronic applications, the QFN packages are always being used because they have low pin-count requirement and it is one of the package technologies that is made with planar copper lead frame substrate [3].

The I/O is different between the variations of QFN package. For conventional single row QFN, it does not satisfy in I/O but DR-QFN does give the good result [6]. Then, to get a better performance in I/O, the multiple-row QFN is the solution [7]. The DR-QFN design is in the middle between single row QFN and BGA style packages. Due to the lead frame based technology, the DR-QFN enables higher I/O count per area of single row QFN packages, and will maintain with similar costing [1].

Consumers nowadays demanded for smaller technological gadgets. Dual row QFN can make the device shrunk into smaller size for the same number of lead frame compare to single row QFN. The lead frame design configuration can affect the thermal properties, the mechanical characteristic in the stress, thermal performance and also the electrical performance. It also can be affected when the thickness of the lead frame is different.

This QFN package has two types of design configurations which is staggered and inline. This paper will show the comparison between both of these configurations and focus on the saw singulation [5]. The saw singulation is proven to be the best way by using the staggered lead design as a solution to the problems that will simplify the assembly flow and reduce unit cost as the result and guarantee a stronger and reliable package [1, 7].

The primary cause of the semiconductor package failure and reliability issues is the thermal-mechanical stress failure in packaging materials [4]. These stresses are because of the combined effect of mismatch in thermal expansion coefficients between the materials. This stress will cause die cracking along the crystallographic plane and finally the semiconductor packages are in failure situation [10].

This study is focused on the mechanical characteristics on stress of the DR-QFN of a 44 lead DR-QFN package on the staggered lead frame design and 48 lead DR- QFN package on the inline lead frame design. The 2D and 3D model of DR-QFN for this project is simulating by using ANSYS software in the steady-state structural analysis. The package size requirements for modeling and simulation were given in methodology section, and both staggered and inline of the configurations were compared through designs and modeling activities.

This paper also has the study of effect of lead frames thickness of DR-QFN package to the thermo-mechanical performance. The paper is organized as follow: the review of the QFN component and the designs are outline in Section II, the proposed materials and designs are outline in Section III, follow by result and discussion are in Section IV. Finally, in Section V is the conclusion of the study.

II. METHODOLOGY

In this study, two types of lead frame design have been simulated and examined. The two types of lead frame design are having different numbers of thickness. The Mechanical APDL System was used in the ANSYS software. In general, the flow chart of this methodology is shown in Figure 1 where it includes the important step in terms of modeling and simulation processes by using ANSYS software.

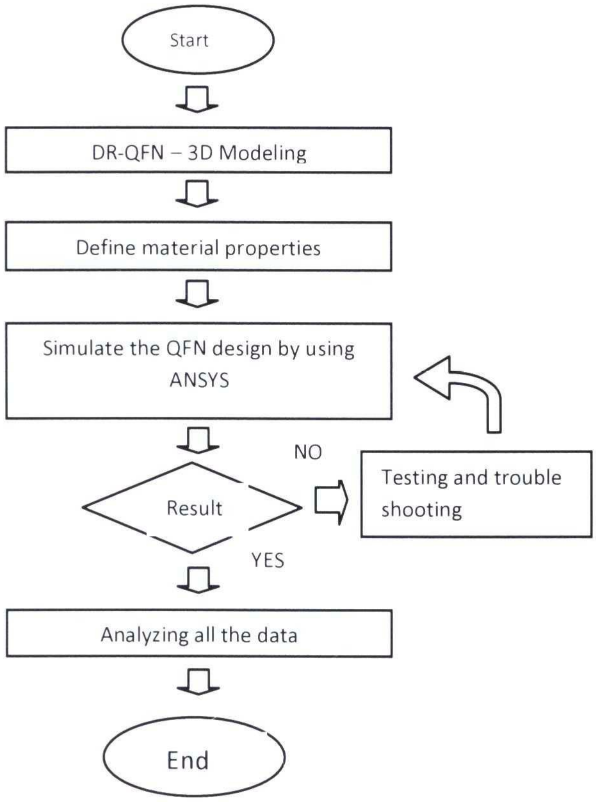


Figure 1. Flow chart of structural analysis of DR-QFN packages

A. *Material Properties*

The structural material properties of the finite element analysis (FEA) of the modelling are listed in Table I [3, 4]. The coefficient of thermal expansion is usually for packaging that undergoes thermal stress and strain analysis [4, 9].

TABLE I. STRUCTURAL MATERIAL PROPERTIES OF QFN PACKAGES.

Material	Young's modulus (GPa)	Poisson's Ratio	Thermal Conductivity (W m.K)	Density ($kg\ m^3$)	Specific heat (J kg.K)	Thermal Expansion (ppm °C)
Lead frame	120.70	0.11	396	8950	385	16.63
Die	28.00	0.26	108	712	712	3.61
Epoxy	1.66	0.26	1.2	2400	800	8.00
Mold Compound	8.00	0.35	0.97	2088	900	3.90

All the material properties in the table above has been applied in both of the designs, staggered and inline and also at the model with different thicknesses of lead frames, 0.15 mm and 0.20 mm.

B. Package Design

A target package size of 5x5 mm with a 0.55 mm for staggered and 0.60 mm thickness for inline configuration was given for a particular application. The JEDEC outline was followed is DGuide4-19D. Apparently the staggered row design has 44 leads, but the inline row design configuration allowed 48 leads. The other details of the final package designs are listed in Table II.

TABLE II. DUAL ROW QFN PACKAGE DESIGN FEATURES.

Design Feature	Value
Package Size	5x5 mm
Package Thickness	0.55 mm (staggered) 0.60 mm (inline)
Lead frame Thickness	0.15 mm (Cu) 0.20 mm (Cu)
Lead Count	44 (staggered) 48 (inline)
Lead Size	0.25x0.25mm
Within Row Pitch	0.55mm
Between Row Pitch	0.3mm
Die size	2x2mm
Pad size	3.2x3.2mm

C. Geometry and FEM Mesh

For the finite element modelling purposes, the QFN model was designed by a fully matrix QFN 2D and 3D that was developed in ANSYS for the numerical simulation. As the geometry of package is square and symmetry, just one-quarter of the package is needed to be model. Two models of QFN packages, which are the staggered and inline dual row configurations, have been simulated for the data of this study. The other two models are added with different number of thicknesses. By using ANSYS software, the FEA modelling was performed into a quarter model of a QFN structure. The element types that were chosen are SOLID Brick 8node 70 at degree of freedom for temperature loading at each node and MESH Facet 200 to make the 2D model become 3D quadrilateral with 4 nodes. Figure 2 shows the lead frame thickness of 0.15 mm for both designs for quarter of DR-QFN. On the other hand, Figure 3 shows the lead frame thickness of 0.20 mm for both designs of quarter of DR-QFN.

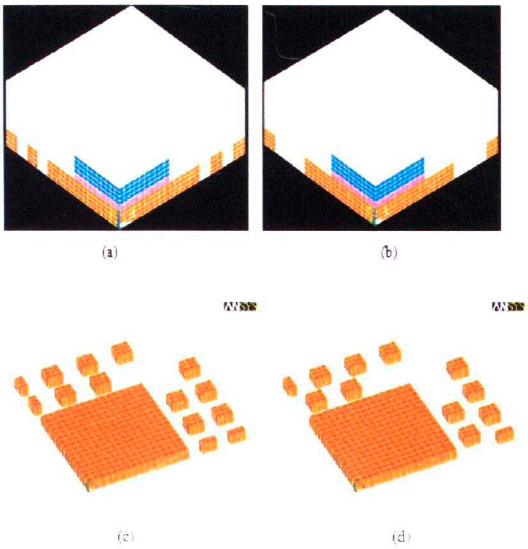
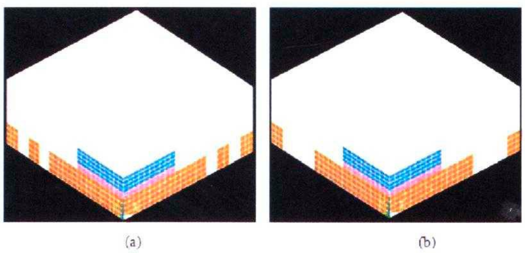


Figure 2. (a) FE mesh of the inline QFN package for lead frame thickness of 0.15 mm, (b) FE mesh of the staggered QFN package for lead frame thickness of 0.15 mm, (c) Lead frame for inline configuration (d) Lead frame for staggered configuration.



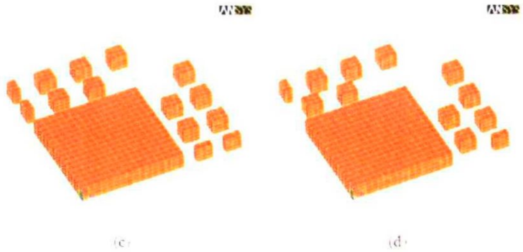


Figure 3. (a) FE mesh of the inline QFN package for lead frame thickness of 0.20 mm, (b) FE mesh of the staggered QFN package for lead frame thickness of 0.20 mm, (c) Lead frame for inline configuration (d) Lead frame for staggered configuration.

D. Thermo-mechanical Modeling

Linear-elastic thermo-mechanical stress process is applied to simulate the model [3]. The temperature is applied directly to lead frame at the DR-QFN packaging. This study applied various values of temperatures to investigate which temperature has made the highest stress value in DR-QFN packages. The temperatures are between 25°C to 300°C.

III. RESULTS AND DISCUSSIONS

The results for different configuration of lead frames are recorded in Table III, Fig. 4 and 5. For different value of thickness, the results are recorded in Table IV, Fig. 6 and 7. In this study, the focus is more on the stress that was distributed between two types of configurations and lead frame thicknesses.

A. Design Modeling

The graph from the simulation results are shown in Fig. 5 with respect to the temperature loading. The values that had recorded are displacement, 1st principal stress and von Mises stress. The starting temperature for both models is at ambient temperature, which is 25°C.

From the simulation results, all loading temperatures show no difference for the displacement, stress and von Mises stress values for both models. But at 150°C, data shows a slightly different value for 1st principal stress, which is about 0.33% in difference. For von Mises stress, at temperature 50°C, 75°C, 125°C and 300°C, data shows different values. The maximum value of stress is occurring at 300°C, which is the staggered have the small value than inline configuration.

In this case, even though both designs have approximately the same values of stress for all the temperature tested, there are still different after calculating the average values of both designs, which are 49.99% for staggered and 50.02% for inline configuration. This is because the temperature is directly applied at the lead frame, not at the die. Die is the component in package that will generate heat when the device is operated.

TABLE III. RESULT FOR DR-QFN PACKAGES IN DISPLACEMENT, 1ST PRINCIPAL STRESS AND VON MISES STRESS USED STAGGERED AND INLINE CONFIGURATION.

Temperature Condition (°C)	Displacement (m)		1st Principal Stress (TPa)		Von Mises Stress (TPa)	
	Staggered	Inline	Staggered	Inline	Staggered	Inline
25	0.13	0.13	58.7	58.7	150	150
50	0.27	0.27	117	117	301	302
75	0.40	0.40	176	176	451	452
100	0.53	0.53	235	235	602	602
125	0.66	0.66	293	293	752	753
150	0.80	0.80	352	353	903	903
200	1.07	1.07	469	469	1200	1200
260	1.38	1.38	610	610	1560	1560
300	1.60	1.60	704	704	1810	1820

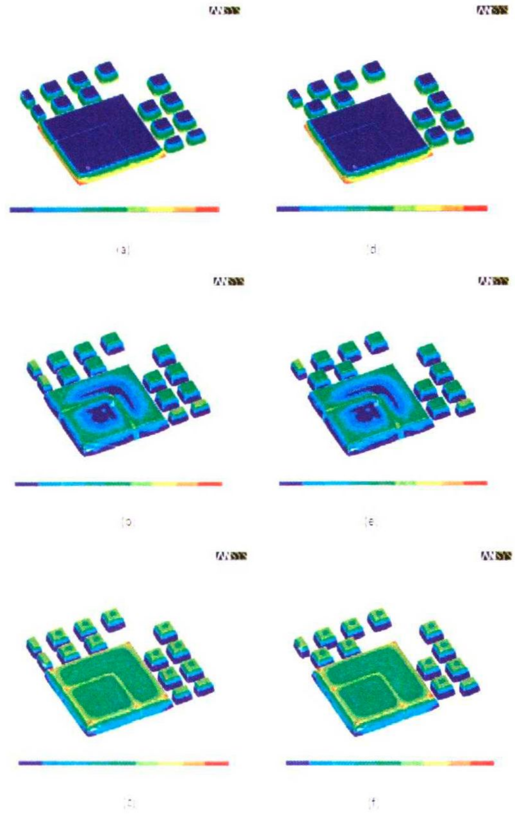


Figure 4. (a) Resulting maximum displacement, (b) maximum 1st principal stress, (c) maximum von Mises stress of inline configuration, (d) maximum displacement, (e) maximum 1st principal stress, (f) maximum von Mises stress of staggered configuration.

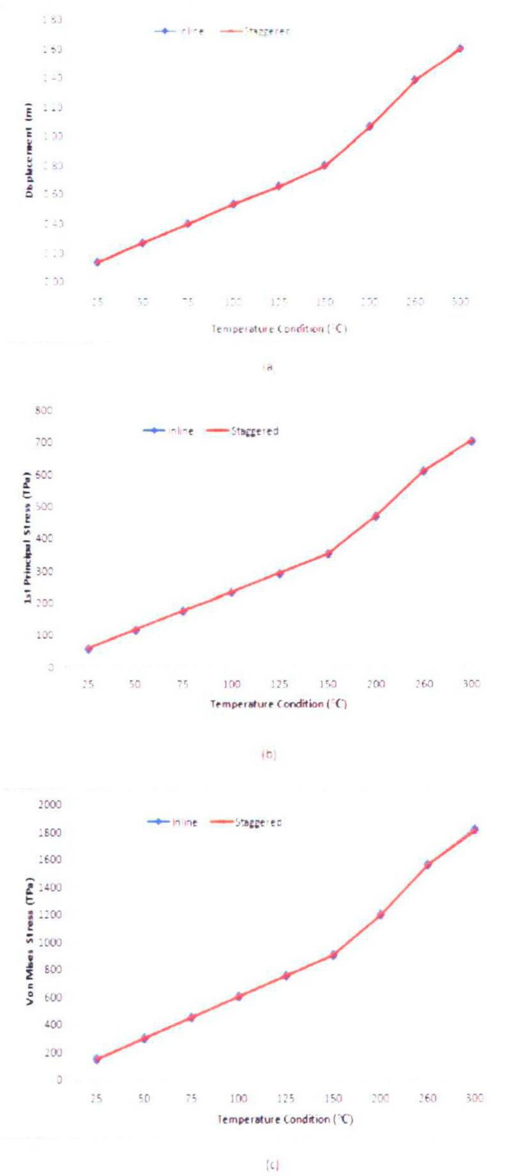


Figure 5. (a) A plot of displacement for different lead frame configuration versus temperature condition, (b) A plot of 1st principal stress for different configuration versus temperature condition, (c) A plot of von Mises stresses for different configuration versus temperature condition.

B. Thickness modeling

The graph of the simulation results are shown in Fig. 7 with respect to the temperature loading. The values that have been recorded were displacement, 1st principal stress and von Mises stress. The starting temperature for both models is at ambient temperature, which is 25°C.

From the simulation results, all loading temperatures show some differences in the displacement, stress and von Misses stress values for both models. For starting temperature condition, at 25°C, the data for displacement shows that about 0.05 m difference between both thicknesses. At 50°C, it shows about 0.09 m difference in value of displacement between both lead frame types. At 75°C, the difference in value of displacement is increased by 0.14 m. Then, at 100°C, it becomes to 0.19 mm the different between thickness 0.15 mm and 0.20 mm. At 125°C, the displacement for thickness of 0.20 mm was higher (which is 0.90 m) than lead frame of 0.15 mm thickness (0.67 m). At 150°C, it shows that the difference of value of lead frame thickness is 0.28 m. In the next temperature loading, the value is increased again, which is 1.07m for lead frame 0.15 mm and 1.44 mm for lead frame 0.20 mm. At 260°C, the displacement value shows the difference between two lead frames is 0.49 m. At 300°C, it is shown that the difference between two thicknesses is slightly high, which is 1.60 m for lead frame thickness 0.15 mm and 2.16 m for lead frame thickness 0.20 mm. The maximum displacement is recorded at this temperature.

In this case, the 0.15 mm lead frame thickness has less displacement compared to the 0.20 mm lead frame thickness. For semiconductor package, when the displacement of the lead frame is larger, it can cause failure to other components in package, such as epoxy, die and mold compound. From the simulation, it can be concluded that the thicker lead frame increase the possibility of package failure such as die cracking and also the delamination effect.

For 1st principal stress, the maximum stress is presented and the maximum temperature was found to be at 300°C, by 803TPa for thickness 0.20 mm and 704TPa for thickness 0.15 mm. When the value of stress increases, it will make the device in high risk for die cracking failure.

For Von Mises stress, the maximum value was obtained at the 0.20 mm lead frame thickness, and value was 1920TPa.The von-Mises stresses can be used to predict failure by ductile tearing. On the other hand, it is not correct for failure by crack propagation, which only depends on the maximum principal stress. A surface crack could create device failure.

TABLE IV. RESULT FOR DR-QFN PACKAGES IN DISPLACEMENT, 1ST PRINCIPAL STRESS AND VON MISES STRESS USED LEAD FRAME 0.15 MM AND 0.20 MM.

Temperature Condition (°C)	Displacement (m)		1st Principal Stress (TPa)		Von Mises Stress (TPa)	
	Staggered 0.15mm	Staggered 0.20mm	Staggered 0.15mm	Staggered 0.20mm	Staggered 0.15mm	Staggered 0.20mm
25	0.13	0.18	58.7	66.9	150	160
50	0.27	0.36	117	134	301	320
75	0.40	0.54	176	201	451	480
100	0.53	0.72	235	268	602	640
125	0.67	0.90	293	335	752	798
150	0.80	1.08	352	401	903	961
200	1.07	1.44	469	535	1200	1280
260	1.38	1.87	610	696	1560	1670
300	1.60	2.16	704	803	1810	1920

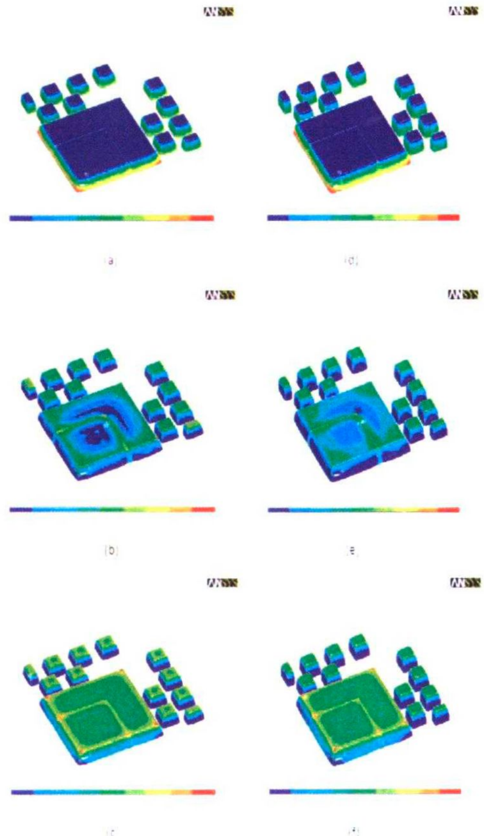
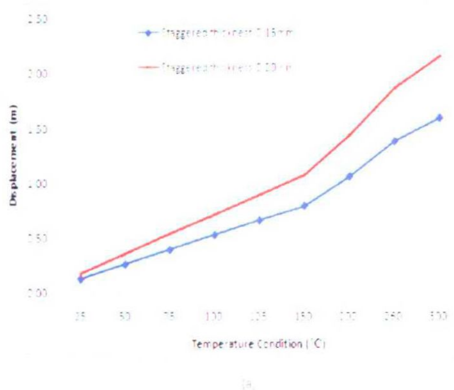
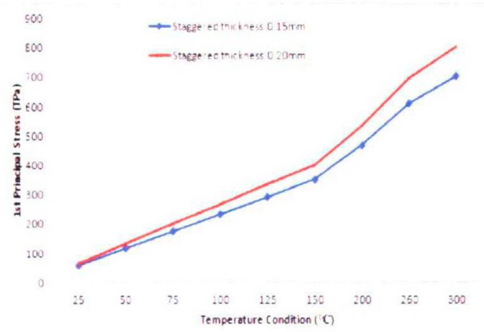


Figure 6. (a) Resulting maximum displacement, (b) maximum 1st principal stress, (c) maximum von Mises stress of staggered 0.15 mm, (d) maximum displacement, (e) maximum 1st principal stress, (f) maximum von Mises stress of staggered 0.20 mm.





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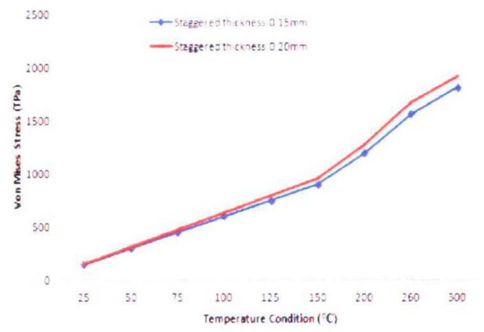

(c)

Figure 7. (a) A plot of displacement for different lead frame thicknesses versus temperature condition, (b) A plot of 1st principal stress for different thickness versus temperature condition, (c) A plot of von Mises stresses for different thickness versus temperature condition.

CONCLUSION

The staggered configuration was predicted to have less value of stress. From the simulation, even though both designs in design modeling have approximately the same values of stress for all the temperature tested, there are still different at maximum temperature and after calculating the average values of both designs, which is the staggered is better than inline configuration.

From the simulation results in thickness modeling, it has been shown that lower value of lead frame can reduce the stress value within the DR-QFN package. However, the increment of stress shows no significant difference from the stress performed by the lead frame thickness of 0.20 mm and lead frame thickness of 0.15 mm but it shown thickness of 0.15 mm is better than 0.20 mm. It seems that the device can be smaller by following the technology and customer demand.

RECOMMENDATION

For further analysis to improve and to produce a good configuration of a DR-QFN package, it is recommended to select the right material that have based on coefficients of thermal expansion (CTE) material which is not too much difference between the material, so that it can perform a lower and better stress value.

Since this project is using the steady-state analysis, it is recommended for future research to conduct the simulation using transient analysis for thermal loading according to the JEDEC standard. It is because of the similarity technique between the reflow processes to the actual application in industries.

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