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FATIGUE ANALYSIS OF MICRO CONTACT CELL VIA CONSTANT AMPLITUDE LOADING

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Abstract

This paper presents the fatigue analysis of the top part of micro contact cell via the constant amplitude loading of new electrical conductive cell contact using micro-structures. The cell is purposely developed to replace the pogo pin used in the assembly line of semi-conductor industry. The new design of micro contact cell utilizes different concept with the typical mechanism of pogo pin nowadays. The development of the cell is using a quasi-solid material as a function of spring mechanism. There are a number of studies giving promising results regarding the design of micro contact cell. This study determines the fatigue failure of micro-contact pins in order to analyze the reliability of the cell under the load of repetitive condition. This study also monitors the fatigue life of micro contact under certain parameters of the constantly repeated loading and suggests the most suitable pin number according to fatigue analysis. The fatigue lives of four (4) models of micro contact cell with different number of pins are studied. The results obtained from the study shows that 16-pin model of micro contact cell is the most reliable and robust design for the repetitive application.

Keywords: Fatigue analysis; electrical conductive cell; micro contact; finite element simulation

Abstrak

Kertas kerja ini membentangkan analisis hayat lesu bagi bahagian atas sel'micro contact' melalui tujahan amplitud malar pada rekaan terkini 'electrical conductive cell contact' yang menggunakan struktur micro. Sel ini telah dibangunkan bagi menukar pengunaan 'pogo pin' di bahagian pemasangan industri semi-konduktor masa kini. Rekaan terbaru ini menggunakan konsep mekanisma yang berlainan berbanding pogi pin. Pembangunan sel ini menggunakan sejenis bahan '*quasi-solid'* sebagai gantian mekanisma 'spring'. Terdapat banyak kajian yang telah dijalankan memberikan keputusan yang baik bagi rekaan sel 'micro contact'. Kajian ini menentukan kegagalan lesu bagi 'mikro contact' pin sel dalaman alisis terhadap ketahanan sel berasaskan beban tetap berulang. Kajian ini juga memantau jangka hayat lesu untuk 'micro contact' dibawah 'parameter' tertentu untuk beban tetap berulang dan mencadangkan jumlah pin yang bersesuaian berasaskan analisis hayat lesu. Jangka hayat lesu untuk empat model yang terdiri daripada berlainan jumlah pin telah dikaji. Kajian mendapati sel 'micro contact' yang menggunakan 16 pin adalah yang paling sesuai dan tahan digunakan dalam keadaan pengunaan yang berulang.

Kata kunci: Analisa jangka hayat lesu; electrical conductive cell; simulasi element tidak terhingga

1.0 INTRODUCTION

There are a number of stages involved to produce a complete Integrated Circuit (IC); for instance, pre-assembly process, the front-end of lines process, and test process. Generally, the test process consists of two different sub- processes; Testing and Scan & Packing. To test the integrated circuit, the device-under-test (DUT) is placed in a test fixture populated with pogo pins that will provide the contact between the device and the printed circuit board. As the microelectronics evolves, the number of input and output ports increases within a given footprint. Thus, smaller pitch of the IC leads requires greater control tolerance for both the pogo pin and test socket housing [1]. There are some improvement for pogo pins with numbers of pattern registered; for instance [2] and [3] in order to match certain dimensions and parameters. Until now pogo pin is still using the same concept of mechanism which uses spring as the medium to absorb the exerted force and to revert the position. Figure 1 shows the typical internal view of pogo pin.

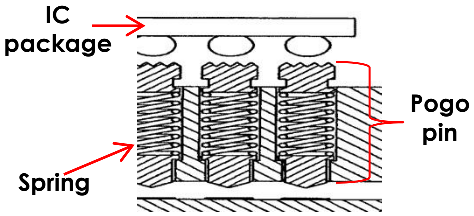

Figure 1 Sectional view of pogo pin [2]

Nowadays the use of pogo pins presents plenty of problems in the test stage of production. The problems may increase the manufacturing lead time and consequently affect the targeted output. In addition, the problem might also increase the number of IC packages failure or defect. The failures may have cause by the indention mark and burr mark on the leads of IC package as shown in Figure 2. The marks will cause the interruption of electricity in the testing process. The interruption is reflected as defection and the IC package is considered rejected [4].

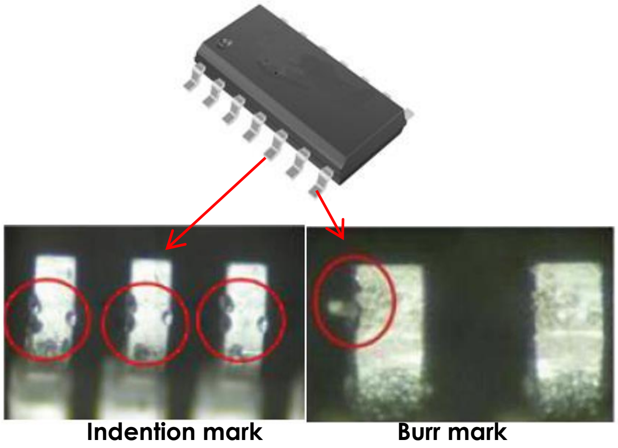

Figure 2 Defection on IC leads [6]

One of the typical problems for pogo pins is tilting. The problem of tilting may come from the nature of existing pogo pins structure where some rooms for offset between pins and the slot are needed. The offset allows the pin to move at certain angles. On the other hand, tilting may also cause by a moving plunger that does not trail the axis of direction and accidentally move sideways. Although the movement in the sideways is comparably small to the movement along its long axis, but it is big enough for the plunger to tilt at certain angle [5] as shown in Figure 3.

Another problem that may happen in pogo pins is spring malfunction. This problem usually occurs for smaller size pogo pin and spring. After undergoing thousands of unit testing cycle, the spring experienced some fatigue issues such as lower reverted spring. The fatigue life cycle of the pogo pin is reduced significantly when the pin breaks and/or foreign particle is trapped in the socket. If a particle is trapped in the slot of pogo pin, it will obstruct is the slot and eventually disturb the movement of the pin. The mechanism of pin movement becomes inelastic and will eventually bend down the IC lead or make a mark on the lead due to lack of force absorption capability.

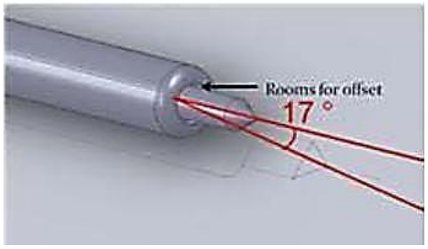

Figure 3 Angle of tilt for pogo pin [5]

New electrical conductive cell contact based on micro-structures column has been designed [5]. The novel idea was innovated to replace the typical mechanism of pogo pin. The use of combination of three different kinds of materials such as polymer, metallic and liquid metal were suggested. The development continues with sets of test according to several parameters [6]. The proposed prototype is based on QFP type of package with pitch size 0.5 mm and foot print dimension 0.25 mm x 0.25 mm. The structure of model is shown in Figure 4.

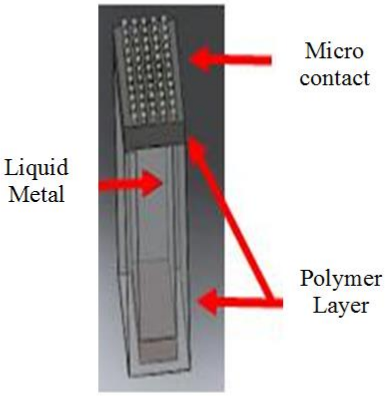

Figure 4 The structure of electrical conductive cell [6]

There are sets of concept tested by following different dimensions, for instance; the length of micro contact column (pin), the number of pins and the thickness of polymer layer. The study found that, the stress produced by the mechanical force is dispersed better when the number of pin was increased. The maximum number of pins that can be applied is up to 25 pins. However, the stress distribution on 16 pins has no significant difference with 25 pins. The analysis focuses on the static study directly on the pins (without polymer layer and liquid metal) in order to monitor the stress distribution. Figure 5 depicts finite elements simulation result for the distribution of overall stress (Von Misses).Moreover from the economical view, more number of pins applied mean more materials and this will certainly increase the complexity to fabricate. Therefore the study concluded that the optimum number of pins is 16.

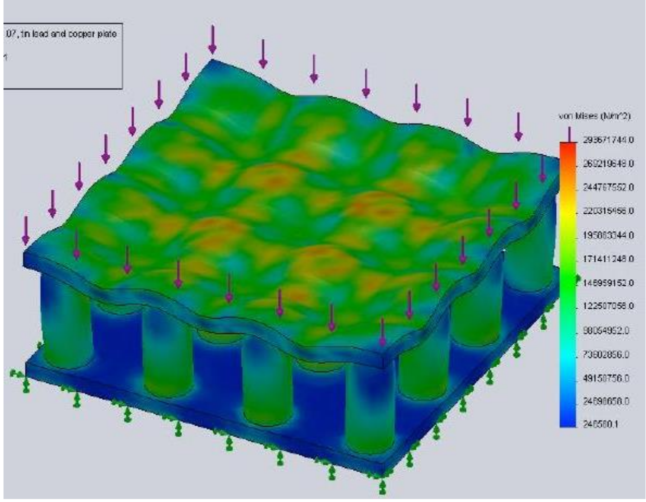

Figure 5 Stress distribution over 16-pin with 0.07mm pitch micro contact [6]

The model of test socket with array of holes to implement the electrical conductive cell contact was developed [7] as shown in Figure 6. The technique [8] to reduce the time taken of simulation has been applied. Five models with different numbers of pin (4, 8, 12, 16 and 20 pins) were setup in order to determine the optimum result. The proposed models as shown in Figure 7 are using the same structure as previous research which uses polymer layer as the housing of the cell and copper plates on top and bottom. The study used gallium as the quasi-solid material. Series of tests to optimise the parameters towards lower resistivity (ohm) and stress produced have been simulated. The study decided that the optimum number of pins 16 and the optimised dimensions for thickness of top plate is 100µm while for the bottom plate is 500µm.

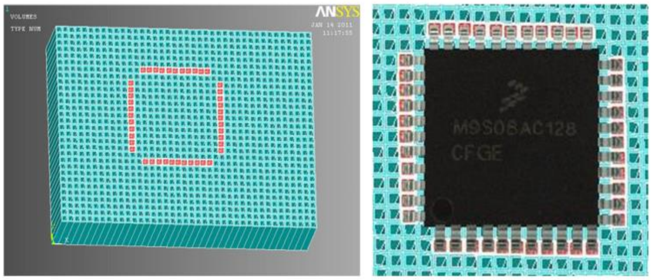

Figure 6 Test Socket with array of holes [7]

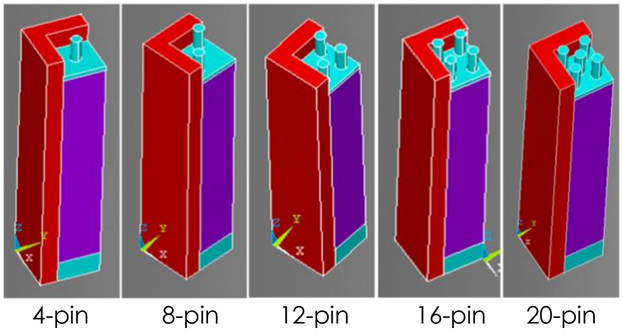
4-pin 8-pin 12-pin 16-pin 20-pin

Figure 7 Quarter-symmetry of the electrical conductive cell [7]

The aim of this paper is to present fatigue analysis on the micro contact cell as an advance study for product reliability. As mentioned earlier, the novel idea of new electrical conductive cell is purposely to overcome the problems of current function of pogo pins. With the nature of functioning for thousands of repetitive usage and the micro size of contact area, the effect of fatigue issues cannot be avoided [5]. This paper presents the fatigue analysis through the constant amplitude loading on the model of 4-pin, 8-pin, 12-pin and 16-pin. The study is purposely performed to monitor fatigue life of the models and to determine the most suitable number of micro contacts through the angle of fatigue failure. The effect of damage on the pins of micro contact due to fatigue stress is also observed.

2.0 MATERIALS AND METHODS

Figure 8 depicts the process flow of the study. As shown in the figure, a case study has been done at the earlier stage of the study to check and validate the needed parameters for the finite element simulation of fatigue study [9]. The micro contact is consists of three parts which are top part, cell and bottom part. The design models of micro contact cell are shown in Figure 9.

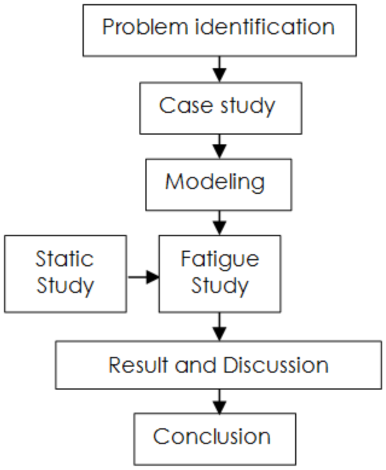

Figure 8 Process flow of the fatigue study

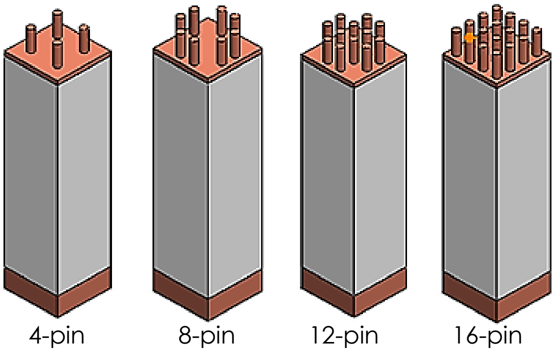

Figure 9 All models of micro contact cell

Table 1 shows the dimension of the micro contact pin. All related dimensions were set to a fix value in order to ensure the credibility of comparison. Therefore this study decided to use the data of the previous research [7] and accepted the suggestion of optimised version of dimensions. There was no involvement of polymer layer in the model since it had been simplified as the boundary condition for both studies in static and fatigue.

Table 1 Model Dimension

Dimension	Unit [µm]
Cell Thickness	0.001
Copper Plate area	250 x 250
Micro contact pin height	100
Micro contact pin diameter	30

2.1 Static And Fatigues Studies

A static analysis needed to be performed as a prerequisite for the fatigue simulation. The purpose of the static study was to determine the maximum displacement of the top part. Furthermore the result of the static study was crucial as one of the important aspects to further the analysis in fatigue study, in which, the model should not fail under the static load. If the failure comes from the static condition, there will be no significance in doing the fatigue analysis because the subject will fail in the very first cycle of load. Data in the static study is then utilized in the fatigue simulation event. By doing this step, only the top plate which contains the micro contact is used as the model in fatigue simulation. 10,000 cycles of fatigue simulation was defined as the minimum loading cycle for all models. With the right material properties implemented in the simulation setup, the simulation result from the study was able to distinguish whether the subject will fail or not under the minimum loading cycle.

2.2 Boundary Condition

The fixtures for static study were applied on three parts (bottom plate, top plate and conductive cell) as shown in Figure 10. The bottom plate was considered fixed for the array of test socket. Therefore, fix fixtures had been applied to the plate. On the other hand, the top plate which consist the micro contact pins was considered as moveable part which was limited to follow the slot of polymer housing. Similar with the conductive cell, boundary condition for the sides that touched the polymer housing are moveable and is likely equal to slider movement. Therefore those parts were assigned with the roller type of fixture. Also shown in the figure is the pressure load which was exerting downward on the top side of the micro contact pins.

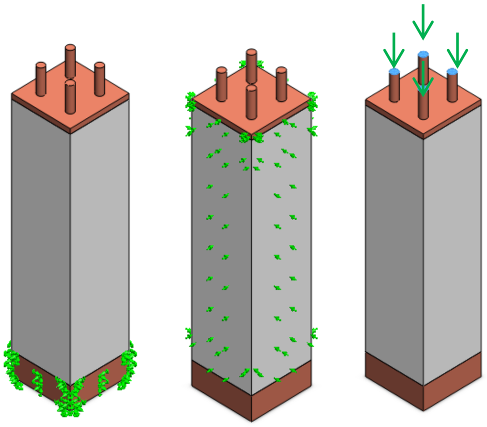

Figure 10 Boundary condition of static study

Meanwhile Figure 11 shows the fixture and external load applied on micro contact plate for the fatigue study. It can clearly be seen that only one part (micro contact plate) is involved in the study. As discussed in the last section, fatigue simulation only needed the maximum displacement data triggered from the other parts (by static study). The underneath surface of the part was linked with the data of displacement from the conductive cell. Meanwhile on the sides of the part, the slider fixture was assigned due to limited movement on the housing slot. The external load (pressure) was applied similar with the static study.

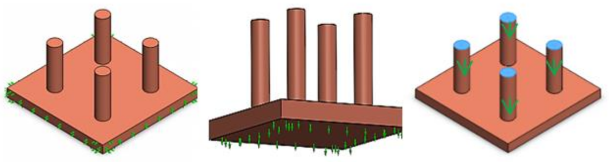

Figure 11 Boundary condition of fatigue study

2.3 Determination Of External Load

In the real situation, there is no exact value that can be evaluated for the exerted force of pogo pin. In general the pogo pin only reverts the force that was exerted from the plunger of the test machine. Via the spring mechanism of the pogo pin system, the force was exerted to the lead of IC package. Due to the complexity of the plunger connected to the test machine, drive force from the pogo pin was given in a range of 65-145 gf [10]. Therefore, in order to ensure minimum risk of failure due to unexpected reaction of force in real situation, the force was decided to be at the highest value, 150 gf which was 5 gf more than maximum value of the range. All the calculated values of exerted force for different pins of micro contact are shown in Table 3. The example of calculation with certain equations used is shown as follow;

Converting the unit of force:

$$\mathrm{F\ (N)} = \frac{150gf}{102gfN^{-1}} = 1.47N$$

Calculation of pressure (external load):

Pressure, $\mathrm{P} = F/\mathrm{A}$

Example for 16 pins:

Each force on the pin, $\mathrm{F} = 1.471\mathrm{N}\ /\mathrm{Numbers\ of\ pin}$

$$F = \frac{1.471}{16} = 0.0919375\ \mathrm{N}$$

The effective area of a pin,

$$A = \pi r^2 = 3.14 \mathrm{\ x\ } 15\mathrm{x}\, 10^{-6} x\ 15\mathrm{x}\ 10^{6}$$
$$= 706.5\ x10^{-12}\ mm^2$$

Therefore, the pressure on a pin is,

$$\mathrm{P} = 0.0919375\mathrm{N}\ /706.5\ x10^{-12}\ mm = 131.13MPa$$

Table 2 External load on each micro contact

Number of pin	4	8	12	16
Pressure (MPa)	520.52	260.26	173.50	130.13

2.4 Material Properties

The top part of the pogo pin was made from copper. To perform fatigue study, S-N curve of copper material was needed. Figure 11 shows the S-N curve for copper [11] and Table 3 shows the selected data of the S-N curve used in the software. The material assigned for both micro contact plate (top plate) and the below plate were copper [9]. The conductive cell assigned was gallium. Material properties of copper and gallium are shown in Table 4 and Table 5 respectively.

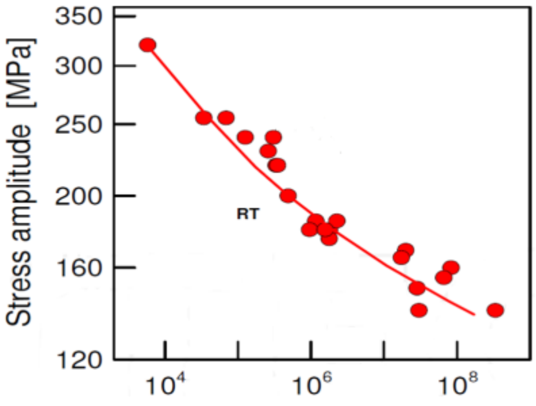

Figure 12 S-N Curve of copper [11]

Table3 Selected data of S-N Curve of copper for fatigue simulation

Alternating stress, MPa	Cycle number, N
320.0	5,000
200.0	500,000
192.0	800,000
164.0	8,500,000
150.2	25,000,000

Table 4 Copper properties [9]

Property Name	Value	Units
Density	8900	kg/m³
Elastic modulus	1.1e+02	GPa
Poisson's ratio	0.37	NA
Thermal expansion	2.4e-5	1/Kelvin
Thermal conductivity	390	W/(m.K)
Specific heat	390	J/(kg.K)

Table 5 Gallium properties [12]

Property Name	Value	Units
Density	6113.6	kg/m³
Elastic modulus	9.81	GPa
Poisson's ratio	0.47	NA
Thermal expansion	11.5e-6 (X-axis) 31.5 e-6 (Y-axis) 16.5 e-6 (Z-axis)	1/Kelvin
Thermal conductivity	390	W/(m.K)
Visco-Elastic	3e-7	m²/s

3.0 RESULTS AND DISCUSSION

Figure 13 until Figure 24 show the results of stress distribution, displacement and factor of safety of all models of micro contact cell through of the finite element simulation of the static study. The equivalent stress of Von Mises presented in Figure 13 until Figure 16. The results showed that the maximum stress indicated on top plate of 4-pin, 8-pin, 12-pin and 16-pin are 548.495 MPa, 311.578 MPa, 203.3 MPa and 150.677 MPa respectively. There was a significant high stress value experienced by the 4-pin micro contact cell compared with the others due to lower contact areas. The lowest stress was recorded on the 16-pin micro contact cell. 16-pin had the largest area of contact load meaning that it could disperse the pressure load better than the others.

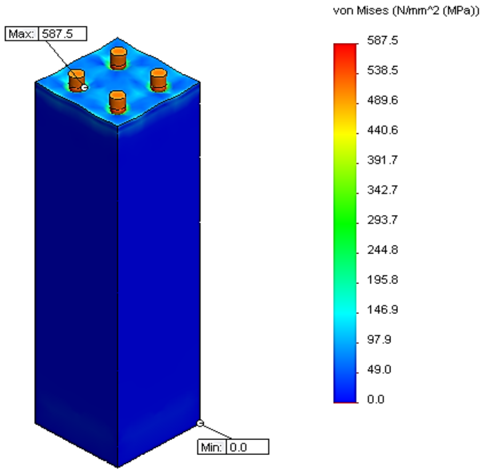

Figure 13 Von Mises tress distribution result of 4-pin micro contact cell

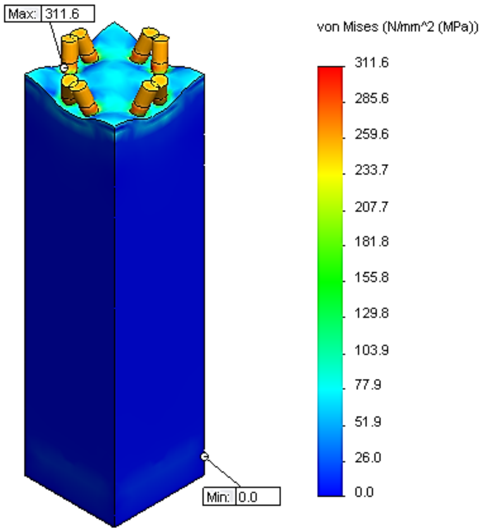

Figure 14 Von Mises tress distribution result of 8-pin microcontact cell

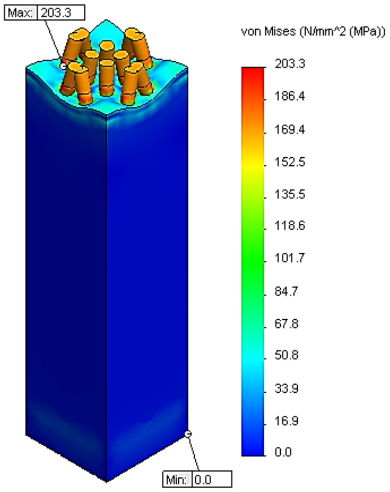

Figure 15 Von Mises tress distribution result of 12-pin micro contact cell

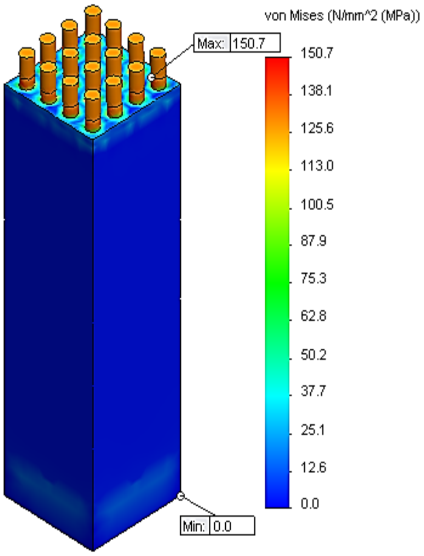

Figure 16 Von Mises tress distribution result of 16-pin micro contact cell

According to the Von Mises yield criterion, yielding occurs when the equivalent stress reaches the yield strength of the material in simple tension. The yield strength for the copper is 269 MPa [12]. Since the maximum value of stress recorded was on the part of copper plate therefore, the stress value of 260 MPa was taken as the value of yielding point. The obtained results showed that the maximum equivalent stress for 4-pin and 8-pin micro contacts exceeded the yield stress. Hence, the parts were considered as fail under the yield criterion. Due to the failure condition, the plastic deformation occurred at the area of high stress distribution.

On the other hand, Figure 17 until Figure 20 show the distribution of total displacement for all the models. It can be seen that 4 pins has the highest value of displacement which was 9.675 x 10^{-4} mm while the lowest value of displacement was on the 16 pins which was 4.95 x 10^{-4} mm as predicted. Since the maximum value of displacement recorded on the pins was on the top plate, there is no issue to use the top plate as the only part for the fatigue study. All the necessary response from other had been mathematically transferred as the displacement data [9]. The data of maximum resultant displacement obtained in this static study will be exported in the fatigue simulation setup as the input parameter.

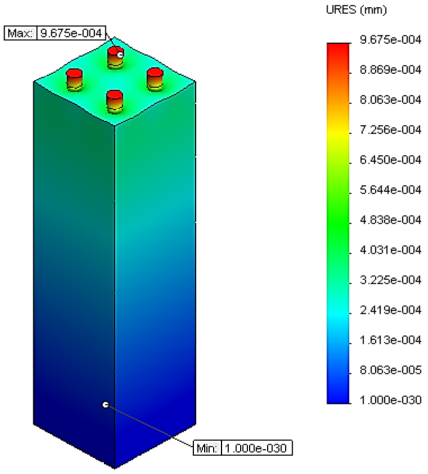

Figure 17 Equivalent displacement distribution result of 4-pin micro contact cell

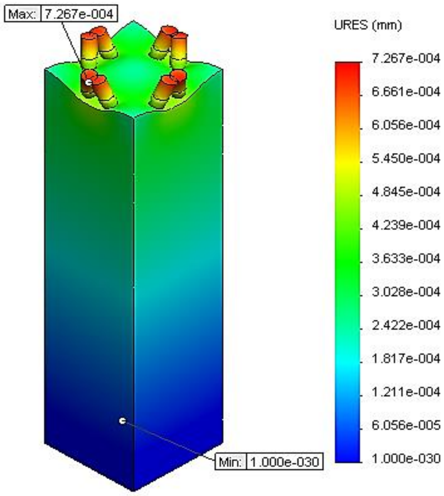

Figure 18 Equivalent displacement distribution result of 4-pin micro contact cell

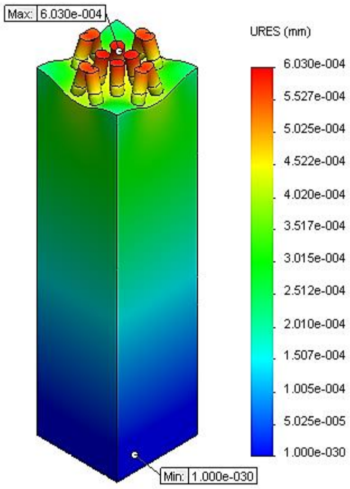

Figure 19 Equivalent displacement distribution result of 12-pin micro contact cell

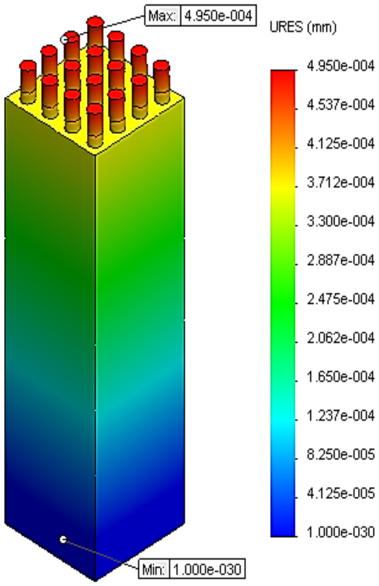

Figure 20 Equivalent displacement distribution result of 16-pin micro contact cell

The result of failure was checked to align with the Von Mises criterion by presenting distribution of localised factor of safety for all models. The results are shown in the Figure 21 until Figure 25. Factor of safety greater than 1 indicates that the design is safe while below than 1 indicates that the design has failed. The minimum value of factor of safety recorded for the 4-pin and 8-pin were 0.44 and 0.83. Since the results below than 1, therefore the structure was indicated as not safe and will experience the plastic deformation.

Meanwhile the cells with 12-pin and 16-pin were recorded to have the higher values of safety factor. The minimum value produced for both 12-pin and 16-pin were 1.27 and 1.72. Since the value were greater than 1, the parts were deemed as safe and will only experience elastic deformation.

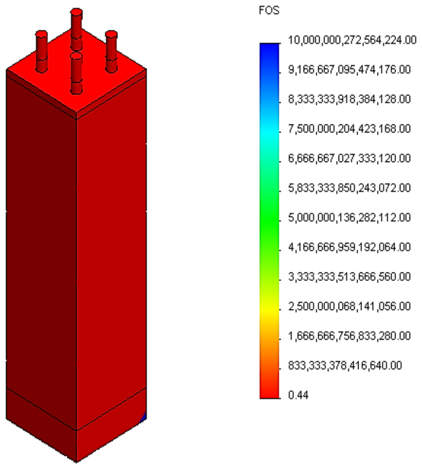

Figure 21 Factor of safety result of 4 -pin micro contact cell

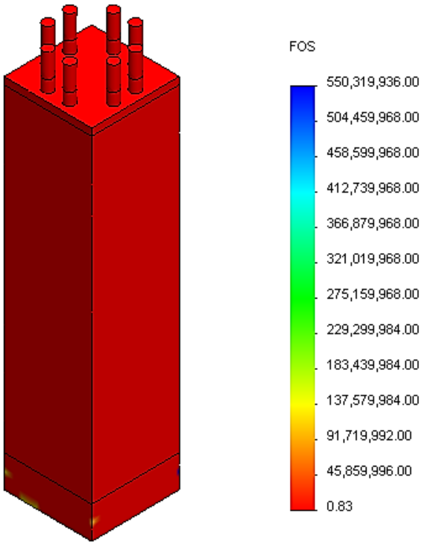

Figure 22 Factor of safety result of 8-pin micro contact cell

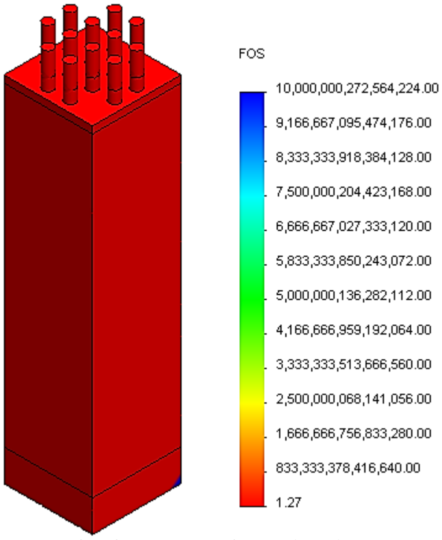

Figure 23 Factor of safety result of 12 -pin micro contact cell

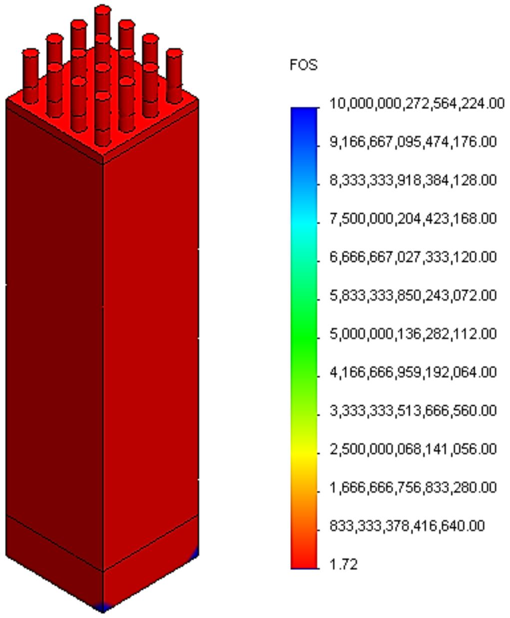

Figure 24 Factor of safety result of 16-pin micro contact cell

Fatigue simulation offered the results of damage percentage and life cycle. Only 12-pin and 16-pin micro cell were selected to advance for fatigue study since the other models had failed during the static analysis. There were some plastic deformation occurred on the pin. The pressures applied had damaged the pin. Figure 25 and Figure 26 show the result of damaged plot for 12-pin and 16-pin. The damaged plot showed the percentage of the assembly's life consumed by the specific fatigue event. Meanwhile the life cycle plot shows the approximate cycles before the part reached the failure. The plot is presented in the Figure 27 and Figure 28.

The stress produced for 12-pin micro contact through the 10,000 cycles event of fatigue simulation was 200.207 MPa (Von Mises stress). The recorded value was lower than the yield point of copper. The damage plot for 12-pin micro contact revealed that the damage was 2.03 percent. Under this circumstances, the minimum life suggested for the 12-pin was 493,559 cycles, after that the micro contact will start to fail.

For fatigue analysis on the 16 pins, the damage percentage obtained was 0.04 percent. The fatigue event of 10,000 cycles only took 0.04 percent of the life of the pin. The suggested minimum life for the pin via the fatigue simulation is 2.46634x10^7 cycles. With more than 1x10^7 of the total life cycle predicted more than 1x10^7 , the product was considered very safe to undergo repetitive motion and contact force since it could be considered to have the infinite life as long as the application work under the fatigue limit [13]. Last but not least Table 6 summarised the results of fatigue study for all models of micro contact cell.

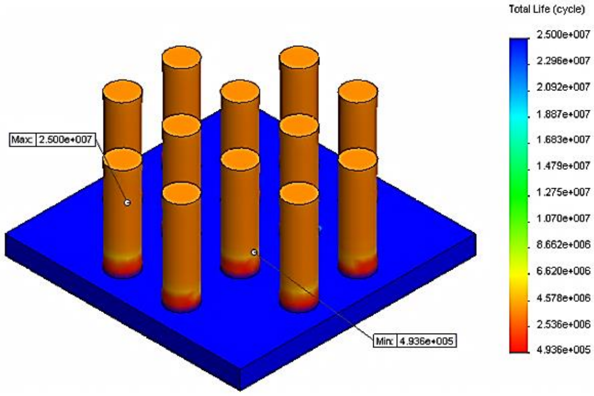

Figure 25 Damage percentage result of 12-pin micro contact cell

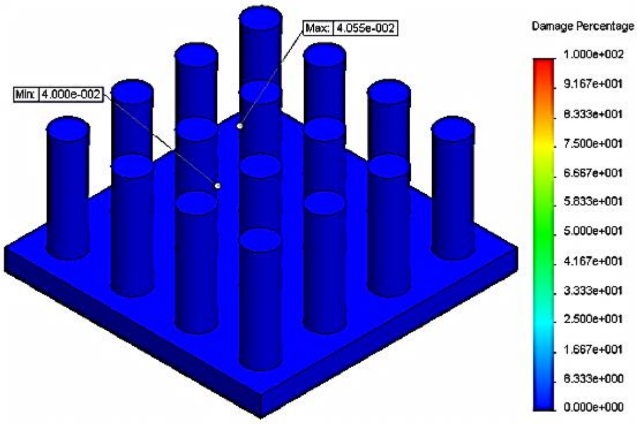

Figure 26 Damage percentage result of 16-pin micro contact cell

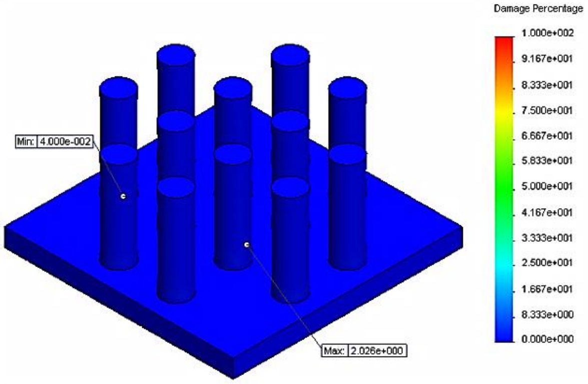

Figure 27 Total life result of 12-pin micro contact cell

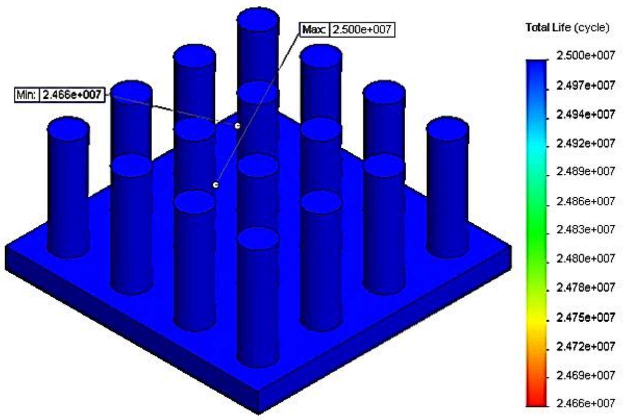

Figure 28 Total life result of 16-pin micro contact cell

Table 6 Summary of result of fatigue study

Number of Pins	Fatigue Parameters	Result
4	Life cycle	NA
	Damage Percentage	NA
8	Life cycle	NA
	Damage Percentage	NA
12	Life cycle	4.93×10^5
	Damage Percentage	2.03%
16	Life cycle	2.47×10^7
	Damage Percentage	0.04%

4.0 CONCLUSION

The fatigue analysis on the electrical micro contact cell had been successfully performed. The static study had been performed to support the parameter needed in the fatigue simulation. Through the finite element simulation method, the fatigue life of 12-pin and 16-pin were predicted. The other models of 4-pin and 8-pin had failed under the Von Mises criterion. The maximum equivalent stress produced for both models (4-pin and 8-pin) in the static study exceeded the yield stress value. The plastic deformation had occurred on the area of pins. With this failure condition, the models were surely failed on the first cycle of fatigue load. Therefore the models could not proceed for the fatigue study. In the fatigue analysis, the damage percentage for 12-pin and 16-pin models had been monitored. As a result, the 16-pin had the highest fatigue life. Moreover 16-pin models will not experience the fatigue failure under the fatigue limit set in the study. Therefore it can be concluded that the most suitable pin number for micro contact cell is 16-pin.

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References

[1] Campbell, R. W. 2003. Material for Test Sockets. Proceeding of Burn-in and Test Socket Workshop. 80-97.
[2] Douglas D. Lefever, Donald W. Harer. 200.Pin block structure for mounting contact pins, retrieved August, 13, 2015 fromhttp://www.google.com.ar/patents/US6252415.
[3] Faull, J. A. 2004. Contactor with Isolated Spring Tips. U.S. Patents,No.6677772.
[4] Liu, W., Pecht, M. & Martens, R. 2001. IC Component Sockets: Applications and Challenges. *International Microelectronics and Packaging Society*. 24(1): 61-67.
[5] Nowshad, A. & Lam, Z. Y. 2008. A Practical Investigation on the Root Causes of the Mechanical Damage of Pogo Pin Type Sockets to IC packages in Final Test. *Proceeding of ICSE*. 393-397
[6] Lam, Zi Yi. 2010. Development of novel micro-contact based test fixture for integrated circuit final testing. Master Thesis, National University of Mala.
[7] Zahra, E. 2010. Mechanical Design and Analysis of Intergated Circuit Test Socket. Master Thesis. UniversitiKebangsaan Malaysia.
[8] Dissanayake, D. Al-Sarawi S. & Abbott, D. *Corrugated Micro-Diaphragm Analysis for Low-Powered and Wireless Bio-MEMS Proceeding of IEEE International Conference on Sensing Technology*. 125-129,
[9] SolidWorks. 2012. SolidWorks Simulation Professional. USA.
[10] Teng, H. C., Chen, M. K., Yeh, C. H., Huang, Y. J. & Fu, S. L. 2007. Study of Contact Degradation in Final Testing for BGA Socket. *Electronic Materials and Packaging*. 1-6.
[11] Ludvic Kunz. 2012. Mechanical Properties of Copper Processed by Severe Plastic Deformation, Copper Alloys- Early Application and current Performance- Enhancing Process, Dr Luca Collini(Ed.) ISBN:978-953-51-0160-4.retrieved August, 13, 2015 fromhttp://www.mateck.de
[12] AJ. Oster. 2013. C-19400 B465 Copper High Performance Alloy, retrieved August, 12, 2015from:http://www.ajoster.com
[13] R. I. Stephens, A. Fatemi, R. R. Stephens and H. O. Fuchs. 2001. *Metal Fatigue inEngineering* (2nd ed). USA: John Wiley & Sons.