Journal of Engineering Research and Reports

16(3): 33-40, 2020; Article no.JERR.60104
ISSN: 2582-2926

Package Substrate Die Pad Roughening Innovative Solution to Strengthened Die Attach Adhesion

Michael D. Capili[1*]

[1]STMicroelectronics, Inc. Calamba City, 4027 Laguna, Philippines.

Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

Article Information

DOI: 10.9734/JERR/2020/v16i317171
Editor(s):
(1) Dr. Ravi Kant, Maharaja Ranjit Singh Sate Technical University, India.
(2) Dr. Tian-Quan Yun, South China University of Technology, China.
Reviewers:
(1) Ayyob Aadbeigi, Azad University, Iran.
(2) Sugondo Hadiyoso, Telkom University, Indonesia.
Complete Peer review History: http://www.sdiarticle4.com/review-history/60104

Short Research Article

Received 14 June 2020
Accepted 19 August 2020
Published 01 September 2020

ABSTRACT

Poor die adhesion to substrate resulting to stray dice issue for the MEMS package was encountered. This die bond failure mechanism has a downstream effect specifically on the mold process. The presence of the stray die resulted to mold compound leakage outside the tool cavity due to planarity not achieved. The mold compound that leaks affected the overall package thickness, thus exposing the wires.

Using the Design of Experiment methodology, the team generated different simulations and validations to resolve the stray die problem. Based on the simulation and experiments, it was established that an optimum substrate roughness is necessary to achieve a better adhesion between the Die adhesive and the substrate.

This paper presents a systematic study on how the substrate roughness can improve the adhesion of Die Attach film (DAF) to the substrate thereby resolving the Stray Die problem. Results showed that the die adhesion strength on the substrate increases as the substrate surface roughness increased from Ra 0.05 um to Ra 1.5 ~ 2.0 mm. Consequently, the rejection rate of stray dice was eliminated. This new learning will be used to establish a standard on surface roughness for substrate-based material that can be applied to new packages.

Keywords: MEMS packages; stray die; substrate; roughened substrate pad.

**Corresponding author: Email: michael.capili@st.com;*

1. INTRODUCTION

Microelectromechanical System (MEMS), is the integration of mechanical elements such as sensors (Sensor Die) and actuators or ASIC Die (Application Specific Integrated Circuit) and electronics on a common silicon substrate through the use of microfabrication technology [1-6]. MEMS commercial applications provide a combination of mechanical functions (e.g., sensing, moving, and heating) and electrical functions (e.g., switching and deciding). These MEMS devices can be applied to the automotive, aeronautics, consumer, defense, industrial, medical, life science, and telecommunication industries this is according to the [7] Advance MEMS Packaging & [8]. An Introduction to Microelectromechanical Systems Engineering [9-12].

One of the major problems encountered, during the initial line stressing stage of the new product is poor adhesion of Sensor primary die on the substrate was experienced per lot. This resulted in a stray dice issue, which was never encountered on other variants of MEMS [13-15]. Hence, several simulations and validations to resolve the stray die issue were conducted. Based on simulation and experimental results, the optimum substrate roughness for respective cases was recommended for better die bonding.

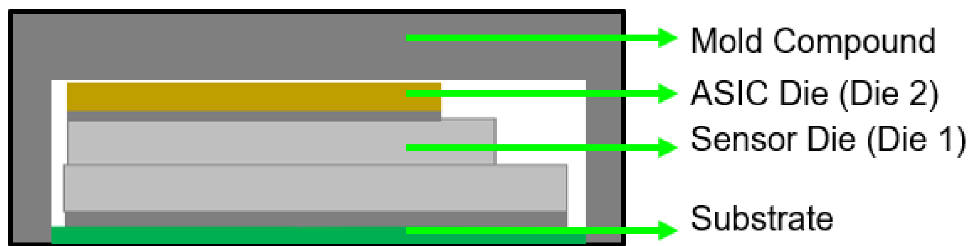


Fig. 1. MEMS Package mechanical elements

2. EXPERIMENTAL DETAILS

During the initial line stressing stage for MEMS MV7U, the top pareto of defects is Stray die at 964 PPM. This is significantly higher compared with other MEMS devices.

An investigation was made on all MEMS devices running in the production to understand why this defect is happening only on the MV7U device. The Structural difference of MV7U among other MEMS devices is the Sensor dies. This device has the largest sensor die size among the MEMS devices. Stray die came from detached/lifted die on a substrate when uncured units were subjected to sudden impact.

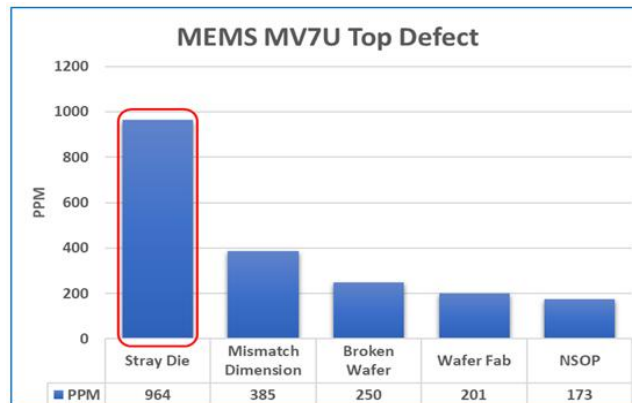


Fig. 2. MEM MV7U Top Defect for Q1 2019

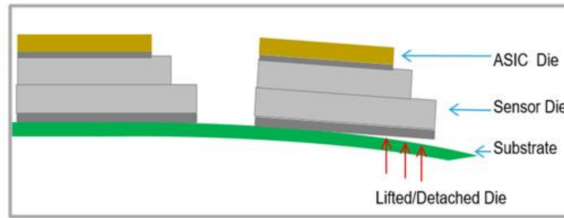


Fig. 3. Stray die failure mechanism

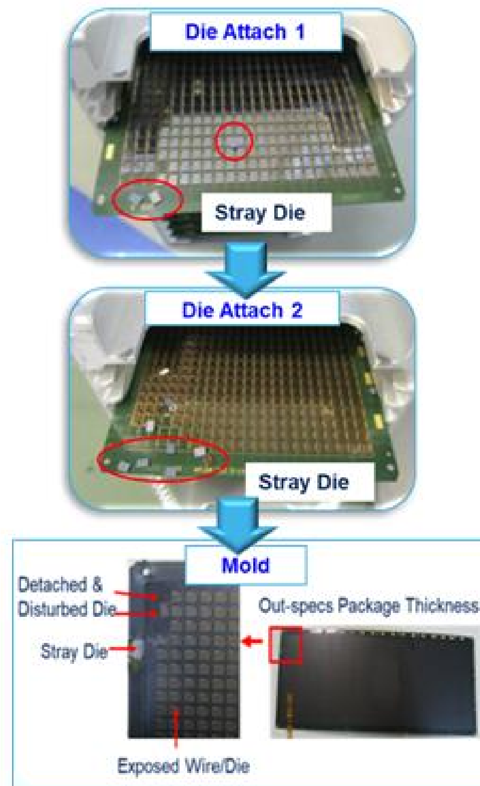


Fig. 4. Stray die failure mechanism at mold process

This die bond failure mechanism also affects succeeding processes [16,17,18]. The presence of stray die on the substrate side rail will produce a gap on the mold tool which will result in out-of-specs package thickness due to mold compound leakage on the substrate rail. A single unit reject at Die Attach will result in 1610x units reject after the Mold process (one whole strip will be rejected).

A process mapping was performed, and the Die Attach process is the focus of the study. Die to attach, also known as die bonding, is the process of attaching (or bonding) a die (or chip) to a substrate or another die. This process can take on many forms and can be applied in different ways.

Die Attach Film (DAF) is the adhesive integrated with dicing film for thin wafers. It is commonly used for the MEMS package because of its uniform thickness, compatibility with the existing assembly process, and bleed-free characteristics.

Identifying Potential Causes From the critical steps identified in the process mapping the team utilizes the Cause and Effect Diagram (Fishbone Analysis). In a C&E Diagram, there were 5 identified potential factors or X's that may affect the output response on the Stray die.

Fig. 5. Process Mapping

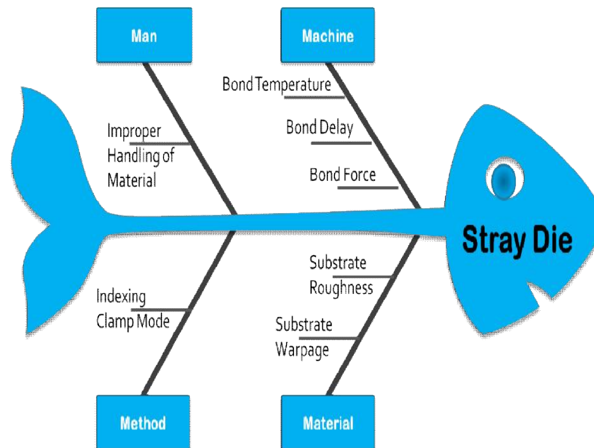


Fig. 6. Cause and effect diagram

Table 1. Statistical test plan

Y (Response)	X (Factor)	True nature of X	Levels of X, if discrete or converted into discrete	Hypothesis Statement		Statistical Test	Beta	Alpha
				Null Hypothesis	Alternative Hypothesis			
Stray Die PPM	Bond Temperature	Continuous	Low 120 °C High 130 °C	Ho: F1=F2 no significant factor	Ha: at least one factor is significant	DOE Factorial Screening	0.1	0.05
	Bond Delay	Continuous	Low 20 ms High 100 ms				0.1	0.05
	Bond Force	Continuous	Low 1 Newton High 1.5 Newton				0.1	0.05
	Indexing Clamp Mode	Discrete	Standard Clamp Soft Clamp				0.1	0.05
	Substrate Warpage	Discrete	Low 0.05 um High 0.20 um				0.1	0.05
	Substrate Roughness	Continuous	Standard Roughened				0.1	0.05

In the next phase, a Validation Plan was made, a statistical test plan was prepared to help analyze statistically the contribution of the remaining 6 factors using statistical test Design of Experiment (DOE) factorial screening.

2.1 DOE Factorial Screening

From the identified 6 potential causes/ factors, a validation plan was performed using a Design of Experiment (DOE) Factorial Screening. This was to identify which among other potential causes of Stray Die would be Most Significant (see in Fig. 6). Screening is used to reduce the number of factors by identifying the Significant factors that affect the response. This reduction allows the experiment to focus on process improvement efforts on the few really important factors or the vital few.

Screening design model :

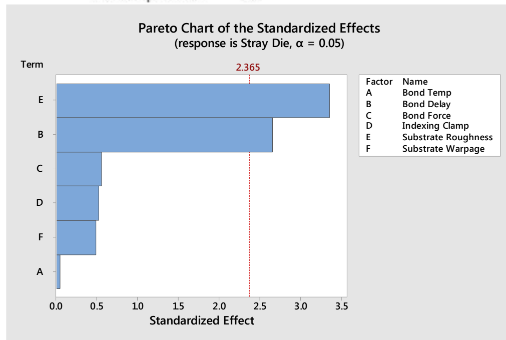
Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	6	133149	22191.5	4.13	0.043
Linear	6	133149	22191.5	4.13	0.043
Bond Temp	1	12	12.4	0.00	0.963
Bond Delay	1	37852	37851.6	7.04	0.033
Bond Force	1	1684	1684.2	0.31	0.593
Indexing Clamp	1	1448	1447.8	0.27	0.620
Substrate Roughness	1	60400	60399.5	11.24	0.012
Substrate Warpage	1	1289	1289.5	0.24	0.639
Error	7	37629	5375.6		
Total	13	170778			

Definitive Screening Design

Design Summary

Factors:	6	Replicates:	1
Base runs:	14	Total runs:	14
Base blocks:	1	Total blocks:	1
Center points:	2		



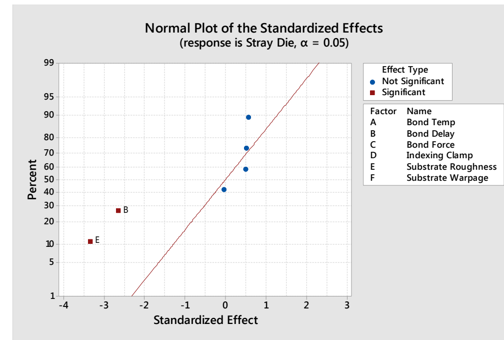


Fig. 7. Design of Experiment (DOE) factorial screening

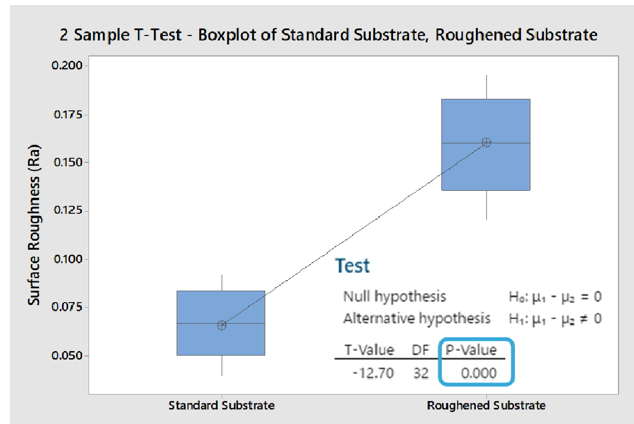
The most significant factors at 95% confidence level are narrowed down to 2. The following factors are significant Substrate Roughness and Bond Delay based on Minitab Pareto and normal plots with P-value less than 0.05.

2.2 Statistical Testing for Substrate Surface Roughness

To back up the DOE Factorial Screening result, we utilized state-of-the-art tools such as Profilometer and Laser Microscopy in the verification of surface roughness. A statistical test was done using a Two-Sample T-test for comparative analysis. Based on the result of measured roughness data, at a 95% confidence level, there is a significant difference in Surface Roughness measurement.

2.3 Statistical Testing for Die Shear Test Response

A statistical test was done in response to the Die Shear Test response using a Two-Sample T-test. Fig. 8 showed at a 95% confidence level that there is a significant difference between



Standard Substrate

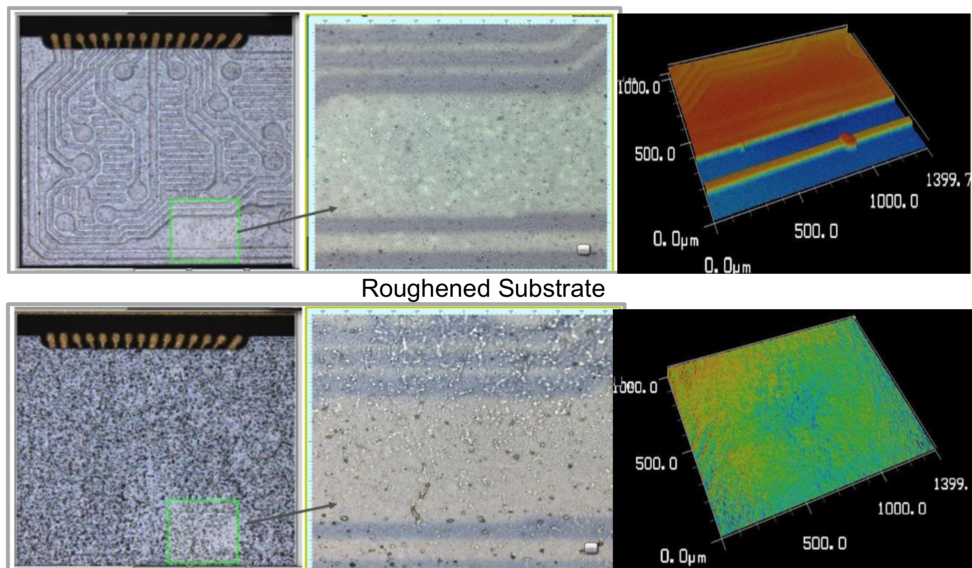


Fig. 8. Two sample T-test for substrate surface roughness (top) and Profilometer images of standard and roughened substrate (bottom)

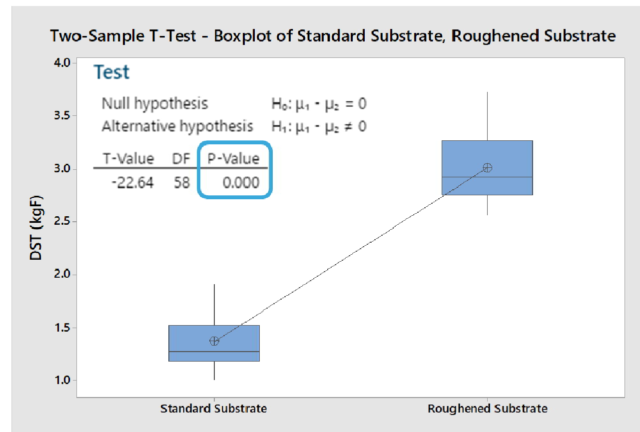


Fig. 9. Two-sample T-test for die shear test of uncured (top)

Standard and Roughened Substrate. Roughened Substrate has higher die shear strength even when partially cured after die bond. Roughened Substrate is significantly better than Standard Substrate.

3. RESULTS AND DISCUSSION

A DOE Response Surface Measurement (RSM) was designed to locate the region of the optimized Substrate Roughness and Bond Delay that will result in less Stray Die PPM.

Based on Minitab's result, the p-value of the model and linear is at 0.000, indicating that the model can provide a significant linear relationship with the response. The p-value of the model and linear is at 0.000, indicating that the model can provide a significant linear relationship with the response. Based on Minitab, the following factors are significant; Substrate Roughness; Bond Delay, and the interaction of the main factor. The Lack-of-fit is significant indicates that the experiment was conducted in the area of the optimum.

The R square value of the model is at 98.17%, indicating that the model has a strong correlation with the response. The Coefficients and collinearity VIF values for all main factors and their interactions remain below, indicating that there is no multicollinearity.

Response Surface Regression: Stray Die versus Substrate ..

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	5	117884	23576.8	130.03	0.000
Linear	2	78391	39195.3	216.17	0.000
Substrate Roughness	1	76383	76383.0	421.26	0.000
Bond Delay	1	2009	2009.2	11.08	0.013
Square	2	36987	18493.7	101.99	0.000
Substrate Roughness*Substrate Roughness	1	36383	36383.2	200.66	0.000
Bond Delay*Bond Delay	1	2327	2326.8	12.83	0.009
2-Way Interaction	1	576	576.0	3.18	0.118
Substrate Roughness*Bond Delay	1	576	576.0	3.18	0.118
Error	7	1269	181.3		
Lack-of-Fit	3	1266	422.0	527.52	0.000
Pure Error	4	3	0.8		
Total	12	119153			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
13.4655	98.93%	98.17%	92.33%

Coded Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	0.60	6.02	0.10	0.923	
Substrate Roughness	-97.76	4.76	-20.52	0.000	1.00
Bond Delay	-15.94	4.79	-3.33	0.013	1.00
Substrate Roughness*Substrate Roughness	72.33	5.11	14.17	0.000	1.02
Bond Delay*Bond Delay	18.56	5.18	3.58	0.009	1.02
Substrate Roughness*Bond Delay	12.00	6.73	1.78	0.118	1.00

Regression Equation in Uncoded Units

Stray Die = 460.1 - 475.8 Substrate Roughness - 2.290 Bond Delay
+ 128.59 Substrate Roughness*Substrate Roughness + 0.01160 Bond Delay*B
+ 0.400 Substrate Roughness*Bond Delay

Fig. 10. DOE Response Surface Measurement (RSM)

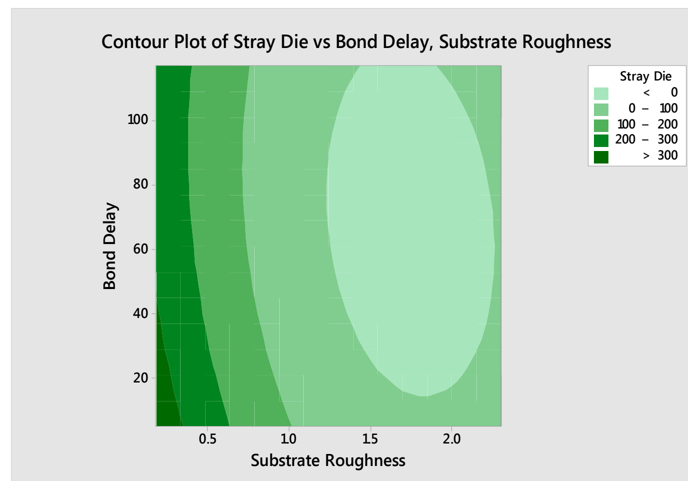


Fig. 11. DOE contours plot response

A contour plot was generated to determine the optimum response between 2 factors Substrate Roughness and Bond delay. In this graph, light color green regions indicate lower Stray die PPM. And the contour profile it points out that the optimum Substrate Roughness is from Ra 1.5 to 2.0 mm while the bond delay is 20ms to 100ms.

Implementation Result after new Substrate roughness criteria were identified through extensive DOE that mitigates the risk of Stray die defects and validations in terms of Quality aspects, large scale evaluations were made through Line Stressing to validate the effectiveness of the corrective actions. The implementation results of optimizing Substrate roughness showed Stray die issue was eliminated. The reject rate was reduced from 964 PPM to 0 PPM for the MEMS MV7U product.

4. CONCLUSION

Surface roughness played a significant role in the adhesion between DAF and Substrate. At a 95% confidence level, experiments indicate that the optimum substrate pad roughness for MV7U is between 1.5-2.0 mm. Implementation of the Roughened substrate solder mask yielded a good mechanical interlocking necessary for good adhesion thereby reducing Stray Die Defect. This new learning will be used to establish a standard on surface roughness for substrate-based material that can be applied to new packages.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and

producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

ACKNOWLEDGEMENTS

First and foremost, we give thanks and glory to our Lord for providing us strength and wisdom to successfully complete this project. We give our deepest gratitude to our family who empowered us to continue and persevere in our work. We would like to recognize also the support ST Microelectronics and our Process Engineering group.

COMPETING INTERESTS

Author has declared that no competing interests exist.

REFERENCES

1. Response Surface Methodology: Process and Product Optimization Using Designed Experiments, Wiley; 4 editions by Raymond H. Meyers, Douglas C. Montgomery and Christine M. Anderson Cook.
2. Quentin Brook, Lean Six Sigma and Minitab: The Complete Toolbox Guide for Business Improvement; 2014.
3. Info Track issue 54 of Semitracks Inc., December by Christopher Henderson; 2013.
4. Micro Electro Mechanical Systems (MEMS) by V. Thiyagarajan from Lakshmi Publications Anna University; 2013.
5. Mems: A Practical Guide to Design, Analysis and Applications by Jan Korvink; Oliver Paul; Jan Korvink December 2006
6. Lean Six Sigma and Minitab (5th Edition): The Complete Toolbox Guide for Business Improvement Spiral-bound – September 1, 2017 by Quentin Brook.
7. Advance MEMS Packaging by John H. Lau, Chengkuo Lee, C. S. Premachandran and Yu Aibin, The McGraw-Hill Companies, Inc. 2010;26-30.
8. An Introduction to Microelectromechanical Systems Engineering, Second Edition by Nadim Maluf, Kirt Williams
9. Problem Solving and Data Analysis Using Minitab: A Clear and Easy Guide to Six Sigma Methodology by Rehman M. Khan
10. Handbook of Silicon Based MEMS Materials and Technologies 3rd Edition Editors: Markku Tilli Mervi Paulasto-Kröckel Matthias Petzold Horst Theuss Teruaki Motooka Veikko Lindroos by Elsevier Published Date; 2020.
11. MEMS A Practical Guide to Design, Analysis, and Applications Book • 2006 Edited by Jan G. Korvink and Oliver Paul
12. Status of Advanced Substrates 2019 report by Yole Développement; 2019.
13. Brophy BL. U.S. Patent No. 7,405,474. Washington, DC: U.S. Patent and Trademark Office; 2008.
14. Epler JE, Martin PS, Krames MR. U.S. Patent No. 7,875,533. Washington, DC: U.S. Patent and Trademark Office; 2011.
15. Khazaka R, Mendizabal L, Henry D, Hanna R. Survey of high-temperature reliability of power electronics packaging components. IEEE Transactions on power Electronics. 2014;30(5):2456-2464.
16. Ho JK. Cvqfn package development. In *2013* IEEE 15th Electronics Packaging Technology Conference (EPTC 2013), IEEE; 2013.
17. Epler J, Martin PS, Krames MR. U.S. Patent No. 8,455,913. Washington, DC: U.S. Patent and Trademark Office; 2013.
18. Priyabadini S, Sterken T, Van Hoorebeke L, Vanfleteren J. 3-D stacking of ultrathin chip packages: An innovative packaging and interconnection technology. IEEE Transactions on Components, Packaging and Manufacturing Technology. 2013;3(7): 1114-1122

© 2020 Capili; This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sdiarticle4.com/review-history/60104