Investigation of integrated factors in the occurrence of copper wire bonding corrosion of semiconductor packages

K. A. Hamid¹, A. H. Badarisman¹, A. Jalar²,³, M. A. Bakar²

¹Nexperia Malaysia Sdn. Bhd, PT No. 12687, Tuanku Jaafar Industrial Park, 71450 Seremban, Negeri Sembilan.  
²Institut of Microengineering and Nanoelectronics, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor.  
³Department of Applied Physics, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor.

Abstract. Copper wire bonding has got attracted attention over gold wire bonding due to its lower cost. However, despite many unique aspects and properties of copper wire bonding, corrosion of copper wire bonding has become a point of interest as it leads to the failure of semiconductor packages. Current and future trends and development in miniaturization and multifunction of the semiconductor packages show semiconductor manufacturers to establish good wire bonding with high reliability. However, this trend becomes a significant challenge in respect of corrosion occurrence. Several studies on the corrosion of copper wire bonding; however, there is no considerable study in the integrated factors leading to corrosion. Therefore, this paper focuses on investigating the corrosion phenomena of wire copper wire bonding, especially wedge bonds. This paper uses a combination of the problem-solving approach for a complex problem. The analysis suggested that the weightage of factors, depending on process parameters and process steps, play a particular role in facilitating or preventing corrosion on the copper wire bonding. Therefore, it is essential to consider these factors when designing assembly process steps and parameters to control corrosion in semiconductor packages.

1 Introduction

Wire bonding technology is considered the most crucial step in establishing the structure and functionality interconnection between chips and substrates of microelectronic packages. Gold (Au) wire has been serving this wire bonding technology for decades due to its excellent workability and stable chemical properties [1, 2]. However, the rise of the gold price has motivated the research and development activity to look for alternative wire materials such as silver (Ag), Aluminium (Al), and copper (Cu) [3-7]. To date, several packaging companies are known to use Cu wires in their production. Although many benefits and advantages of using Cu wire have been highlighted and discussed, the issues of cracking at the wire bond interface are often reported [8, 9], probably because of humidity or temperature. Reports have also shown the more inferior reliability issue of Cu wire bond than Au wire bond has also been reported in the presence of halides in conventional molding compounds and encapsulant materials [10]. This material degradation-related issue, delamination, including corrosion, is more pronounced due to the difference in electrochemical potential between the lead frame and Cu in electrolytes [11, 12]. Although the corrosion mechanism for the system may be predicted, however, from manufacturing or assembly process steps, every step must play its role in further preventing or delaying the corrosion mechanism [13].

The most common degradation of the material is corrosion, and it has many causes contributed by internal and external factors. The reaction is the reaction of the material with the environment in its operating. Without understanding corrosion, factors will lead to failure in proper monitoring and inability to control, contributing to lacking the risk of corrosion mitigation. The cost-efficient of copper wire bonding superseded gold wire bonding. The copper wire and the factor in corrosion is a new study as the corrosion can lead to the catastrophic failure of semiconductor packages. Several studies report the corrosion of copper wire bonding; however, there is no significant study analyzing the integrated factors leading to corrosion. Therefore, this paper focuses on investigating corrosion phenomena of wire copper wire bonding, especially on wedge bond, and continue from the other work. In a nutshell, the approach is analyzing big data and linked with the design of the experiment. Further

¹Corresponding author: azmn@ukm.edu.my

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI. Published under licence by IOP Publishing Ltd
analysis suggested that weightage of factors, depending on process parameters and process steps, play a particular role in facilitating or preventing corrosion on the copper wire bonding. Therefore, it is essential to consider these factors when designing assembly process steps and parameters to control corrosion in semiconductor packages.

Many factors contributed to the corrosion in the semiconductor packages. The leading theory is based on the package robustness and directly link to the package strength. It corresponds with the molding-plating system. In this theory, delamination is a vital output response that indicates the package strength. Lower delamination correlated with better package robustness. The corrosion theory based on the delamination will allow the contamination through the chemical ingestion, subjecting the copper wire corrosion. Thus, package delamination is a characteristic under investigation. The delamination is the enabler to package corrosion. This analysis focuses on package corrosion to confirm integrated factors identified by big data analysis [14] as the probable factors that contributed to the package corrosion. This paper's motivation is to understand the integrated factor that contributed to the package corrosion within the package strength theory at the molding-plating process system. This paper aims to prove that big data is applicable in problem-solving a complicated issue such as corrosion. The confirmation run through the design of the experiment is critical in establishing this notion.

2 Methodology

The complex problem under investigation is the corrosion of copper wire, and the investigation boundary is limited to the mid-end process of the molding-plating process system. The theoretical basis is the package robustness concept based on the strength-energy theory. This theory is related to the molding-plating system as the molding system provides the package strength, and the plating system provides the energy to package. The design of the experiment will evaluate the impact of multivariate factors and output response. The design of the experiment coefficient of determination (R squared) indicates the model's strength. In addition, the correlation between factors is under study as any factor correlation is a value indicator toward the integrated factors and indicates the strength of the model. The focus area of study is the molding-plating system. The factors for the design of experiment confirmation run are from the other work on the big data. The additional work has confirmed the capability of big data from the Maximal Information-based Nonparametric Exploration (MINE) algorithm to determine the potential factors that contributed to corrosion from the massive manufacturing database. These factors will be subjected to the confirmation design of the experiment to test the correlation to the delamination percentage. The delamination percentage has been identified as the output response because it is the source of chemical ingestion stated in theory [15]. The test vehicle for this study is a small outline transistor (SOT) with an outline dimension of x mm width x y mm length x z mm height, with a standard copper leadframe and tin plating on the leads. This study will focus on epoxy molding compound, lead frame, and molding temperature, which occur directly after encapsulation in a standard back-end process, as indicated in Table 1.

Table 1. Design of experiment factors used in the study.

| Design of experiment factors          | High      | Low       |
|--------------------------------------|-----------|-----------|
| EMC Spiral Flow                      | 30 inch   | 23 inch   |
| Leadframe Roughness (Ra)             | High Ra   | Low Ra    |
| Molding Temperature (°C)             | 220       | 200       |

The design of the experiment (DOE) used to investigate the effect of multiple factors consisted of the epoxy molding compound, lead frame, and molding temperature. The DOE runs are shown in Table 1. The DOE comprises eight runs of 3, 2-level factors: molding temperature, lead frame roughness, and epoxy material compound (EMC) spiral flow. The molding temperature selected from the big data results from the other work. The lead frame roughness and EMC spiral flow were chosen for package delamination. The output response of this DOE will be the delamination. The delamination percentage is the delaminated area divided by the compound adhesion surface area. The observation was measured after the molding process. The output response is the delamination percentage (%) derived from the C-scan with the scanning acoustic microscopy (SAM) machine of Sonoscan D9000 with a 50-75 GHz frequency range.
3 Results and discussion

The result of the design of the experiment is the modeling of the factorial regression in Table 2 and Table 3. The model coefficient of determination R squared is 95%, and the threshold for an acceptable model is 70%. Hence the design of the experiment model is sufficient to explain significant factors that cause the delamination % variation. The result of the design of the experiment, as shown in Fig. 1 of the Pareto Chart of Standardized Effects. The result suggested that the main factors molding temperature and the lead frame roughness have exceeded the 12.71 significant thresholds. It is the indication of significant factors toward the package delamination. The EMC spiral flow did not pass the limit, and the 2-way interaction also did not pass the threshold indicating non-significant factors toward the package delamination.

Table 2. Analysis of Variance from factorial regression SCAT% versus temperature, leadframe.

| Source             | Df | Adj SS  | Adj MS  | F-value | P-value |
|--------------------|----|---------|---------|---------|---------|
| Model              | 3  | 51.855  | 17.285  | 28.57   | 0.004   |
| Linear             | 2  | 47.650  | 23.825  | 39.38   | 0.002   |
| Temp               | 1  | 25.205  | 25.205  | 41.66   | 0.003   |
| LF                 | 1  | 22.445  | 22.445  | 37.10   | 0.004   |
| 2-way interactions | 1  | 4.205   | 4.205   | 6.95    | 0.058   |
| Temp ° LF          | 1  | 4.205   | 4.205   | 6.95    | 0.058   |
| Error              | 4  | 2.420   | 0.605   |         |         |
| Total              | 7  | 54.275  |         |         |         |

Table 3. Model Summary from factorial regression SCAT% versus temperature, leadframe.

| S      | R-sq  | R-sq (adj) | R-sq (pred) |
|--------|-------|------------|-------------|
| 0.777817 | 95.54% | 92.20%     | 82.16%      |

Fig. 1. Pareto chart of the standardized effects.
The horizontal line, which is parallel to the x-axis, indicated then there is no main effect. Each factor level affects the response differently, which means it is the same across all factor levels. The non-horizontal indicated there is a main effect. The different levels of the factor affect the response differently. The steeper the slope of the line, the higher the magnitude of the main effect. The main effects plot for SCAT% (delamination %) is shown in Fig. 2. The molding temperature, the spiral flow of the epoxy molding compound, and the lead frame roughness seem to affect the delamination % because the line is not horizontal. Molding temperature and lead frame roughness have a higher delamination % than the EMC spiral flow. The combination of higher molding temperature and lower delamination correlated with higher delamination %. Therefore, the molding temperature has an inverse relation with lead frame roughness resulted in higher delamination %. It indicates that the integrated factor contributed to high delamination %, which is associated with corrosion. The reference line represents the overall mean. The Fig. 3 and Fig. 4 show the highest delamination at the high molding temperature, and the lowest lead frame roughness compared with the other corner plot, which indicated the lower delamination. This combination is the highest probability contributed to the higher delamination toward the package corrosion.

Fig. 2. Main effect plot for SCAT%.

Fig. 3. DOE Combination 2 corner plot.
Fig. 4. Contour plot of SCAT% versus leadframe, molding temperature.

4 Conclusion

The design of experiment result indicated that the combination of the integrated factors identified from the big data. This is established that the combination of big data and design of experiment has tremendous potential as the identification of probable root causes. Further analysis suggested weightage of factors, depending on process parameters involved together with process steps, play a particular role in facilitating or preventing corrosion on the copper wire bonding. It is essential to consider these factors when designing assembly process steps and parameters to control corrosion in semiconductor package.

The authors would like to acknowledge the financial support provided by the Ministry of Higher Education, Malaysia (grant number FRGS/1/2020/TK0/UKM/013) and Nexperia Malaysia Sdn Bhd (grant number RR-2019-001) Universiti Kebangsaan Malaysia for collaboration work and technical support.

References

1. Zulkifli M N, Harun F and Jalar A Microelectron. Int. 36 62-7 (2019)
2. Zulkifli M N, Jalar A and Harun F IEEE Transactions on Components, Packaging and Manufacturing Technology 9 763-9, (2019)
3. Gan C L and Hashim U J. Mater. Sci. 26 4412–24 (2015)
4. Zhong Z. Microelectron. Reliab. 51 4–12 (2011)
5. Appelt B K, Tseng A, Chen C and Lai Y Microelectron. Reliab. 51 1–20 (2011)
6. Yu C, Chan C, Chan L and Hsieh K Microelectron. Reliab. 51 119–24 (2011)
7. Guo R, Hang T, Mao D, Li M, Qian K, Lv Z and Chiu H J. Alloys Compd. 588 622–27 (2014)
8. Hang C J, Wang C Q, Mayer M, Tian Y H, Zhou Y and Wang HH Microelectron. Reliab. 48 416–24 (2008)
9. Lee C C and Higgins L M 60th Electronic Components and Technology Conference 1–4 342–49 (2010)
10. Boettcher T, Rother M, Liedtke S, Ulrich M, Bollmann M, Pinkernelle A, Gruber D, Funke H J, Kaiser M and Lee K 12th Electronics Packaging Technology Conference, Singapore, 585–90 (2010)
11. Tan JS, Lee W W, Afdzaluddin A, Hamid K A, Jalar A and Bakar M A IEEE Regional Symposium on Micro and Nanoelectronics (RSM) 73-5 (2021)
12. Ahmad Taufiq N N, Hamid K A, Badarisman A H, Ideris H, Jalar A and Bakar M A IEEE Regional Symposium on Micro and Nanoelectronics (RSM) 69-72 (2021)
13. Shan X and Pecht M Corrosion in Microelectronics Packages. In: Lau J.H. (eds) Thermal Stress and Strain in Microelectronics Packaging. Springer, Boston, MA. 803–49 (1993)
14. Hamid K A, Bakar M A, Jalar A and Badarisman A H International Conference on Electrical, Communication, and Computer Engineering (ICECCE), 1-4 (2021)
15. Azizan S and Omar G IEEE CPMT Symposium Japan (ICSJ), 49-54 (2019)