Board Level Reliability of Automotive eWLB (embedded wafer level BGA) FOWLP

by

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ABSTRACT

With shrinking chip sizes, Wafer Level Packaging (WLP) is becoming an attractive packaging technology with many advantages in comparison to standard Ball Grid Array (BGA) packages. With the advancement of various fan-out Wafer Level Packaging (FOWLP) designs, this advanced technology has proven to be a more optimal and promising solution compared to fan-in WLP because of the greater design flexibility in having more input/output (I/O) and improved thermal performance. In addition, FOWLP shows superior high-frequency performance with its shorter and simpler interconnection compared to flip chip packaging. eWLB (embedded wafer level BGA) is a type of FOWLP that enables applications requiring smaller form factor, excellent heat dissipation and thin package profiles. It also has the potential to evolve into various configurations with proven yields and manufacturing experience based on over 8 years of high volume production.

This paper discusses the recent advancements in robust board level reliability performance of eWLB for automotive applications. A Design of Experiment (DOE) study will be reviewed which demonstrates improved Temperature Cycle on Board (TCoB) performance with experimental results. Several DOE studies were planned and test vehicles were prepared with the variables of solder materials, solder mask opening/Cu pad size of redistribution layer (RDL) design, copper (Cu) RDL thickness and under bump metallurgy (UBM), and Cu pad design (NSMD, SMD) on a printed circuit board (PCB). With these parametric studies and TCoB reliability tests, the test vehicle passed 1000x temperature cycles (TC). Daisy chain test vehicles were used for TCoB reliability performance in industry standard test conditions.

I. INTRODUCTION

Semiconductor packaging has a significant impact on the overall device performance. Traditional packaging technologies are reaching their limits in terms of the performance, size and scalability required to meet the needs of emerging applications. The automotive integrated circuit (IC) market will outgrow by two times the rest of the IC market in the next 10 years. Market researchers forecast that automotive semiconductors will occupy over 15% of the total semiconductor market by 2025.

Currently 8000 electronic components are used for Audi A8 and over 2000 electronic parts are used in automobiles on average [1] and 80% of innovations in automotive technology comes from semiconductors. Current and future demands of automotive microelectronics in terms of performance, power consumption, integration and reliability at a required cost are met by developing advanced silicon process technology, innovative packaging solutions based on chip and package system co-design, low cost materials, reliable interconnect technologies, and advanced assembly and test.

Emerging WLCSP market of Automotive Applications

The emergence and evolution of any package technology is driven by market trends as experienced by the end application. Currently the primary automotive packaging solution is leaded or laminate wirebonding which is over 90% of the total market.

The Wafer Level Chip Scale Package (WLCSP) is the smallest possible package size since the final package is no larger than the required circuit area. Wafer Level Packages (WLP) has experienced significant growth since its introduction due to the small form factor and high performance requirements of mobile consumer products.

WLCSP is already well adopted in the automotive market for cabin or infotainment applications as well as 77GHz radar sensors with FOWLP [2,3]. The range of applications continues to expand with the ultimately larger wave in the development of next generation automotive capabilities, i.e. electrical vehicle (EV) and autonomous driving car. The market share of current WLCSP volume is expected to double in the next 3-5 years. The car radar market is expected to grow 28% annually (2015-2022) and reach 200M$ in packaging and assembly.

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Advanced Wafer-Level Technology: eWLB/FO-WLP for mmWave & Automotive Radar Applications

With increasing performance of Si-based front-end technologies, wireless systems at millimeter wave (mmWave) frequencies become more and more important [3-5]. Adaptive Cruise Control (ACC) radar system at 77 GHz [6, 7], point-to-point radio link at 60 GHz or high resolution radio imaging at 94 and 140 GHz [8] are only a few examples of applications observed for upcoming markets. With frequencies increasing beyond 10 GHz, the impact of packaging on the overall electrical performance of the IC becomes increasingly important. Therefore, the availability of high performance packages for monolithic microwave integrated circuit (MMIC) is crucial for the continued development of commercial mmWave applications.

Various approaches for mmWave packaging solutions have been published based on Rogers 4350 substrate surface mount-type (SMT) package for 1-40 GHz applications [9] or 77 GHz ceramic SMT package using an electromagnetic coupling as second-level interconnects [10]. However, since they use standard laminate-based integration techniques, the resulting package is rather bulky and costly.

A very promising solution for mmWave packaging is eWLB package technology [11, 12]. It is based on an embedded device technology with fan-out redistribution. The thin-film redistribution layer (RDL) of the eWLB enables very flexible and highly customizable package designs. The length of the redistribution lines is in the range of the die size.

eWLB can achieve minimum interconnection length and excellent electrical performance up to mmWave frequencies. The conversion gain and the noise figure of the mixer affect the performance of the overall system. Therefore, a high transmission performance of a mmWave signal is very important in the design of a package.

In a number of cases, eWLB achieved a 20~40% reduction in package size as compared to other packaging solutions and over 50% volume reduction because of its slim and smaller form factor. For radio frequency (RF) and high-frequency devices, eWLB showed less parasitic electrical interference, therefore, it also significantly improved overall device performance. In one example, a 77GHz SiGe mixer packaged as an eWLB achieved excellent high-frequency electrical performance due to the small contact dimensions and short signal pathways which decreased parasitic effects [13].

Below are some factors why eWLB is a strong solution for mmWave or high frequency applications compared to other packaging solutions, such as flip chip or wirebonding.

- Interconnection length: eWLB enables integration where the distance has to be as short as possible (loss increase with distance) to minimise loss (assuming both technologies have the same material loss).
- Conductance loss: Plated Cu in organic substrate materials has large surface roughness because of its base materials roughness used to improve adhesion and plating process control. eWLB uses a thin-film fab process for seed-layer and a well-controlled Cu plating to achieve a smooth Cu RDL surface which is more effective for skin effect in high frequency ranges.
- Dielectric loss: Organic substrate materials have high losses in mmWave range and also heterogeneous material sets bring complexity in terms of electrical behaviors. eWLB has molding compound and low-loss dielectric materials, therefore, less dielectric loss would be achieved.
- Design flexibility: eWLB provides more design flexibility for less routing interference with fine line width(LW) and line spacing(LS) capability (less than 10/10um LW/LS).

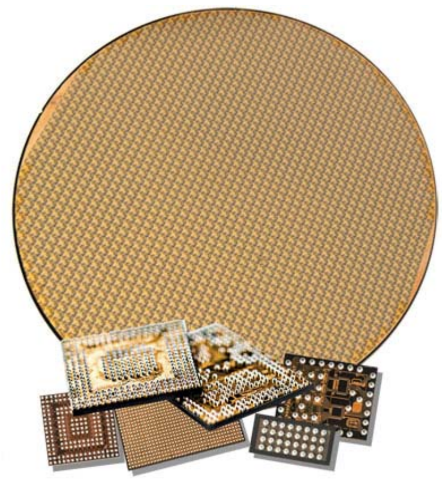

Figure 1. 300mm eWLB carrier and various units.

Radar technology in vehicles is facing a change in terms of assembly and manufacturing. Traditionally, bare die technology is used where the die is attached with adhesive to the PCB and electrical contact is performed by wire bonding on the board. This challenging assembly has to endure several critical process steps: from bare die handling to shaping wire bonds in a way that RF requirements are met[14].

Using standard surface mount device (SMD) packaging technology is one key element for the change from a quite complex and expensive solution to an easy-to-use and, therefore, inexpensive and affordable product. The eWLB package is offering these properties and it is proven in several mmWave applications.

In this study, we focused on 2nd level reliability of the solder joint regarding temperature cycling as one of the major requirements of automotive applications, which requires a higher reliability spec of AEC-Q100 Grade1. Hence, studying design parameters and material properties is of special interest for systems with eWLB packages. Thorough and systematic parametric study and tests were conducted to investigate and understand the TCoB reliability of eWLB in automotive applications.

II. EXPERIMENTAL WORKS

Test Vehicle Specification

The test vehicle was designed in a 9x9mm package size and assembled with the eWLB process based on advanced dielectric materials, as previously reported, for robust package reliability [15].

For the Design of Experiment (DOE) study, several package design factors were investigated, such as PCB Cu pad structure (SMD/NSMD), solder mask opening size, thicker Cu RDL in eWLB, with UBM and a new solder alloy. As per DOE, several different samples were prepared accordingly.

Table 1. Test Vehicle Specification (Reference).

Items	Specification
PKG size	9x9mm
Die Size	6x6mm
Ball Pitch	0.5mm
Ball Dia	0.3mm
IO No.	230
UBM	No
Cu RDL No.	1 layer
Die Thickness	440µm
PKG Thickness	770 µm

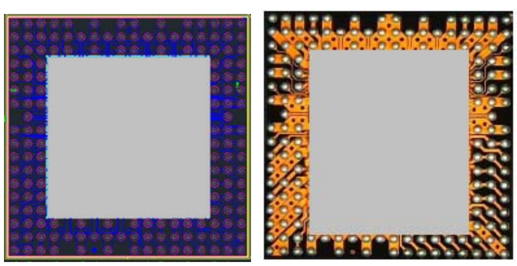

Figure 2. PKG drawing and micrograph of test vehicle of 9x9mm eWLB.

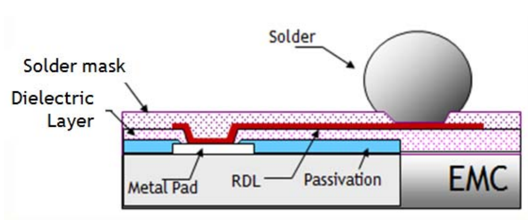

Figure 3. Schematics of eWLB package.

Component Level Reliability

eWLB test vehicles were assembled and prepared for component level reliability tests. Table 2 shows the package level reliability test conditions in this study.

All tested eWLB parts successfully passed industry standard package level reliability of AEC-Q100 Grade1 [16]. For temperature cycling test, eWLB with advanced dielectric material passed JEDEC TC_B (-55/125^{o}C) and TC_C (-65/150^{o}C) conditions.

Table 2. Package Level Reliability Results of eWLB with advanced dielectric material.

Test	Q100 Test Condition	Test Conditions
PC Pre-Cond	JEDEC J-STD-020	MSL1 24h bake @ 125°C 192h @ 30°C/60%RH Reflow simulation (3times) with Lead free profile Tmax=260°C
THB Temp Humidity Bias	JESD22-A101/A110	Ta=85°C, 85%RH 1000h with bias
AC Auto-clave	JESD22-A102/A118	P=2.08atm Ta=121°C, 96h
TC Temp. Cycling	JESD22-A104	Ta = -55/+150°C 1000 cycles
PTC, Power Temperature Cycle	JESD22-A105	Ta = -50/+150°C 1000 cycles
HTSL, High Temp. Storage Life	JESD22-A103	Ta=150°C 1000h
THS, Temp Humidity Storage	JESD22-A101	Ta=85°C, 85%RH 1000h without bias
HAST Highly Accelerated	JESD22-A102/A118	130°C / 85% RH, no bias, 96hrs

Board Level Reliability

For board level reliability tests, a daisy chain eWLB was assembled and mounted on the PCB as shown in Fig. 4. This daisy chain connection in the test vehicle was designed to cover the most significant interconnections to investigate solder joint reliability effectively even though not fully connected. Various DOE samples of different eWLB designs with advanced dielectric materials were prepared and tested for TCoB board level reliability. Those samples were tested in JEDEC TCoB condition (-40/125^{o}C, 2 cycles/hr). The PCB was prepared with RF materials with FR4 8-layer board of 1.2mm total thickness. eWLB daisy chain test vehicles were attached on the PCB with solder paste for surface mounting. The PCBs were loaded into the TCoB chamber with event detector for on-line failure monitoring.

Table 3 shows board level reliability test results of DOE study of eWLB packages.

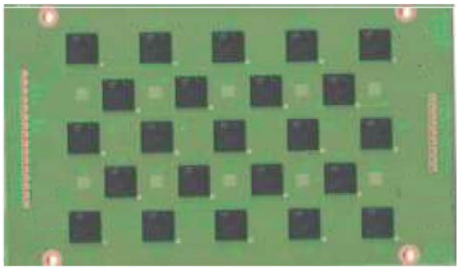

Figure 4. Board level reliability test board with surface mounted eWLB packages.

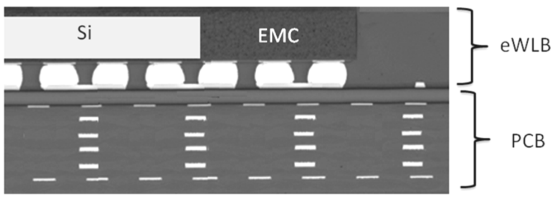

Figure 5. Schematics of cross-section of eWLB mounted PCB of Fig. 6.

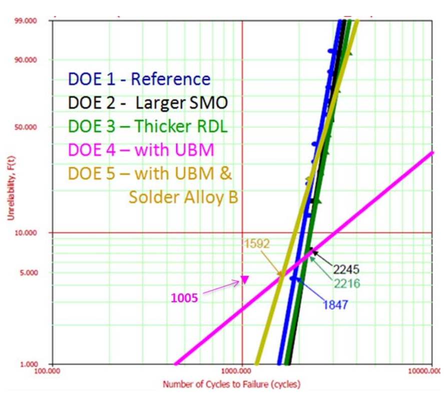

Figure 6. Weibull plot of TCoB DOE study with NSMD PCB. Each no. indicates the first failure cycle in each DOE.

Table 3. Summary of TCoB reliability test results of DOE studies.

		First Failure Cycles	
		SMD	**NSMD**
DOE1	Reference	1452	1847
DOE2	Larger solder mask opening	1388	2245
DOE3	Thicker RDL	1763	2216
DOE4	With UBM	964	1005
DOE5	With UBM and Solder Alloy B	1002	1592

The results from the DOE TCOB reliability studies are summarized below:.

1. NSMD showed improved TCoB performance for all DOE studies beside a case with UBM.
2. Larger solder mask opening was effective to improve results for the NSMD pad.
3. Thicker Cu RDL showed 15~20% improvement in TCoB test.
4. UBM did not effectively improve TCoB in this study. Need to further investigate and understand this behavior. There would be further failure analysis work required to understand mechanical failure mechanism.
5. With UBM and a new solder alloy B, it increased TCoB in NSMD pad.

III. CONCLUSION

eWLB technology is an important wafer-level packaging solution that will enable the next-generation of automotive radar applications with its unique superior high frequency electrical performance thanks to its materials and structure. In this study, 9x9mm eWLB reliability was studied and reported of component level and TCoB reliability with various DOE studies. 9x9mm eWLB with advanced dielectric materials passed AEC-Q100 grade 1 package level reliability as well as board level reliability. Several DOEs were studied to investigate design factors for an improvement of TCoB performance.

Furthermore, the differentiating factors with eWLB are the ability for heterogeneous integration; to integrate passives like inductors into the various thin-film layers, active/passive devices into the mold compound, and achieve 3D vertical interconnections for new SiP and 2.5D/3D packaging solutions. eWLB technology provides more value-added performance and promises to be a new packaging platform that can expand its application range to various types of automotive and mmWave applications, such as antenna on package or antenna in package.

References

1. Berthold Hellenthal, "Inventing the Automotive Future", Semicon Korea, Jan 2016, Seoul, Korea
2. http://www.infineon.com/cms/en/applications/automotive/safety/adas/automotive-radar/NXP
3. http://www.nxp.com/pages/multi-channel-77-ghz-radar-transceiver-chipset:MR2001
4. A. P. S. Khanna, "Broadband Wireless Access Trends and Challenges", 29th European Microwave Conference (EuMC 1999), Oct. 1999.
5. K. Ohata, "Millimeter-Wave IC Packaging Technology – State of the Art and Future Trends", Gallium Arsenide Applications Symposium (GAAS 2000), Oct. 2000.
6. H. Sobol, "Microwave Industry Outlook – Microwaves for Telecommunication Systems",

IEEE Trans. Microwave Theory Tech., vol. 50, no. 3, pp. 1037–1038, March 2002.

7. I. Gresham, N. Jain, T. Budka, A. Alexanian, N.Kinayman, B. Ziegner, S. Brown, and P. Staecker, "A Compact Manufacturable 76–77 GHz Radar module for Commercial ACC Applications", IEEE Trans. Microw. Theory Tech., vol. 49, no. 1, pp. 44–58, Jan. 2001.
8. M. Schneider, "Automotive Radar – Status and Trends", German Microwave Conference (GeMIC 2005), April 2005.
9. A. Tessmann, S. Kudszus, T. Feltgen, M. Riessle, C. Sklarczyk, W. H. Haydl, "A 94 GHz Single-Chip FMCW Radar Module for Commercial Sensor Applications", IEEE MTT-S International Microwave Symposium (IMS 2002), June 2002.
10. K. Kitazawa, S. Koriyama, H. Minamiue, and M. Fujii, "77-GHz-Band Surface Mountable Ceramic Package", IEEE Trans. Microw. Theory Tech., vol. 48, no. 9, pp. 1480–1491, Sept. 2000.
11. M. Brunnbauer, E. Fürgut, G. Beer, T. Meyer, H. Hedler, J. Belonio, E. Nomura, K. Kiuchi, K. Kobayashi, "An Embedded Device Technology Based on a Molded Reconfigured Wafer", 56th Electronic Components and Technology Conference (ECTC 2006), June 2006.
12. M. Brunnbauer, E. Fürgut, G. Beer, T. Meyer, "Embedded Wafer Level Ball Grid Array (eWLB)", 8th Electronics Packaging Technology Conference (EPTC 2006), Dec. 2006.
13. M. Wojnowski1, M. Engl1, B. Dehlink:; G. Sommer', M. Brunnbauer, K. Pressed and R. Weigel, "A 77 GHz SiGe mixer in an embedded wafer level BGA package", Proceedings of 58th Electronic Components and Technology Conference, 2008. ECTC 2008. (2008)
14. G. Haubner, W. Hartner, S. Pahlke, M. Niessner, "77 GHz automotive RADAR in eWLB package: From consumer to automotive packaging", Microelectronics Reliability, September 2016, DOI: 10.1016/j.microrel.2016.07.104
15. Seung Wook Yoon, Tom Strothmann, Yaojian Lin and Pandi C. Marimuthu, "Robust Reliability Performance of Large size eWLB (Fan-out WLP),' iMAPS Device Packaging Conferences 2013, Pheonix, Arizona (2013)
16. http://www.aecouncil.com/AECDocuments.html