# Through Mold Vertical Interconnect Formation in FOWLP using conductive paste

Serine Soh Siew Boon, Soon Wee David Ho, Norhanani Jaafar

Institute of Microelectronics, A*STAR (Agency of Science, Technology and Research)
2 Fusionopolis Way, #08-02 Innovis Tower, Singapore 138634
sohsb@ime.a-star.edu.sg, +65-6770-5776

**Abstract**

Through-Mold Interconnects (TMI) have been widely adopted and integrated into Fan-out Wafer Level Packaging (FOWLP) for semiconductor packaging technology. With the increasingly I/O counts and higher performance applications, the incremental density of lateral and vertical interconnects is essential to enhance the interconnections development in circuit miniaturization. This paper will discuss an alternative cost-effective and versatile approach, conductive paste via-filling, to form vertical interconnections between the embedded electrical routes to the external connections of the FOWLP. This approach promotes the ability in forming of vertical interconnections with greater critical dimension and depths, as compared to the existing Through-Mold Interconnect (TMI) formation methods.

## Introduction

The current vertical interconnect formation methods for 3D integration in Fan-Out Wafer Level Packaging (FOWLP) includes laser-drilled vias, vertical wire-bonding and copper pillars. Through-Mold-Via (TMV) are laser drilled vias in molded Epoxy Molded Compound (EMC). The Through-Mold Interconnection applied in Mold-First process flow, refers to the connection, formed through the plated laser drilled vias, from the top of the package to the embedded RDL (Re-Distributed Layer) in the package. While the RDL-First method is an implementation of molding electro-plated copper pillar and embedded RDLs, with mechanical back-grinding to expose the tip of copper posts for backside connections. Both TMV and copper pillar Through-Mold Interconnects (TMI) methods can be used for integration for Package-On-Package (PoP) stackings, as illustrated in Figure 1. The three types of vertical Through-Mold Interconnections (TMIs) namely, (a) Laser-drilled Through-Mold Via, (b) Vertical Wire-bonding and (c) Copper Pillar interconnect; as depicted in Figure.2. The vertical wire-bonding approach was patented by Kulicke and Soffa Industries Inc [3], while the copper pillar approach commonly used in RDL-First, would require high-resolution thick photoresist to patterned for the formation of the copper pillars. These TMIs have been developed to integrate the electrical interconnections from the embedded pads to the exterior of the package. On contrary, via-filling with conductive paste is developed adopting the laser-drilled via approach. Instead of electro-plating into the Through mold via (TMV), the conductive paste is filled into the created vias. The conductive paste via-filling could be an economical solution to form vertical Through Mold Interconnects (TMI), in the Epoxy Mold Compound (EMC) substrate. This alternative solution offers mechanical anchoring in the TMV, between the granular-coarse TMV sidewall and the fillers present in the paste, illustrated in Figure. 3(a) and 3(b), respectively. The conductive filled-via integrates the embedded pads and the connection pads on the two different ends, through the conductive vertical interconnection. The conductive paste via-fill method targets to provide TMI with greater diameter and depth, greater than 200um since the existing formation methods are capable to provide for diameter and depth below 200um.

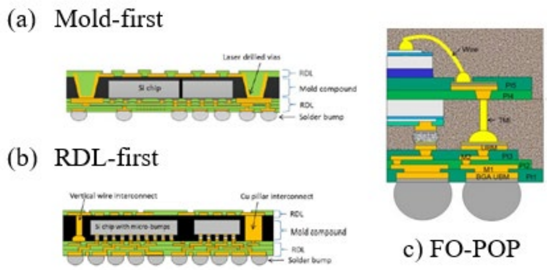
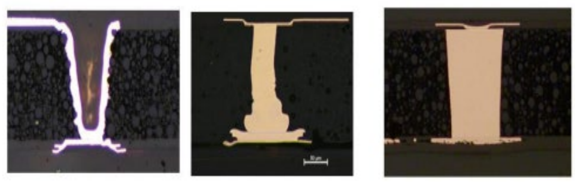
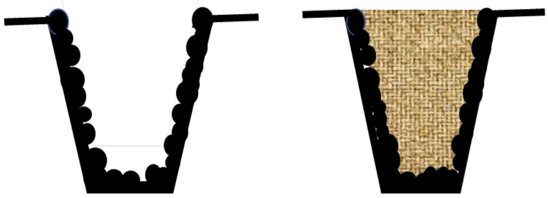



**Figure 1. The application of different TMI in different packaging approaches. (a) TMV in Mold-First (b) Copper pillar in RDL-First and (c) Combination of Copper Pillar and Vertical Wire-bonding in FO-PoP [1] [2],[4]**



(a) (b) (c)

**Figure 2. The three types of Through-Mold Interconnects (a) Laser-drilled Through Mold Via, (b) Vertical Wire- bonding and (c) Copper pillar interconnect [1]**



3(a) 3(b)

**Figure 3(a) and 3(b) illustrates the laser drilled via and the conductive paste filled-via.**

**Experimental process of Conductive paste Via-fill TMI formation**

The fabrication process adopts the Mold-first method. with the backgrinding process to thin down the EMC Epoxy Mold Compound) wafer to the desired thickness for laser-drill process to create the vias for the conductive paste to fill in, as illustrated in Figure 4.

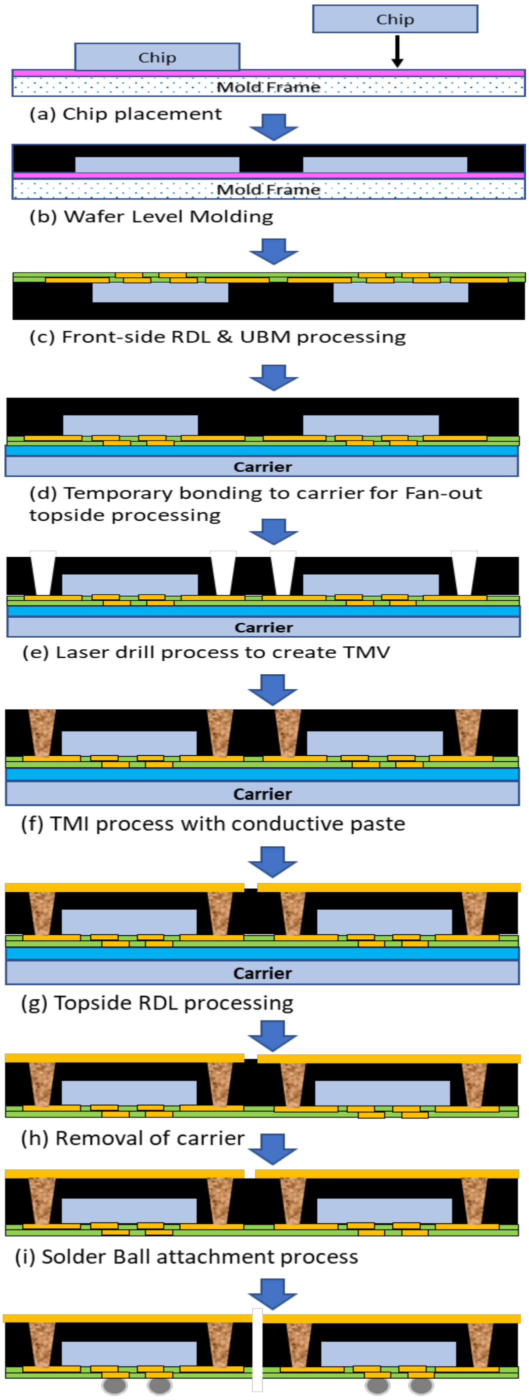



**Figure.4 The Mold-First process flow with conductive paste via-filling.**

The re-constituted wafer is bonded onto the carrier and undergo the laser drilling process to create vias for the conductive paste to be filled in. The laser-drilling process created vias with critical dimension of 100um – 200um with depth of 200um – 500um to evaluate via-filling process. A plasma clean is conducted on the mold compound substrate before the via-filling process. Common paste-printing processes include manual paste-printing and vacuum printing. Figure 5 illustrates the vacuum printing process that prints the paste into the vias of the substrate, by applying pressure onto the squeegee and it moves forward and return to scrape away excessive paste on the substrate.

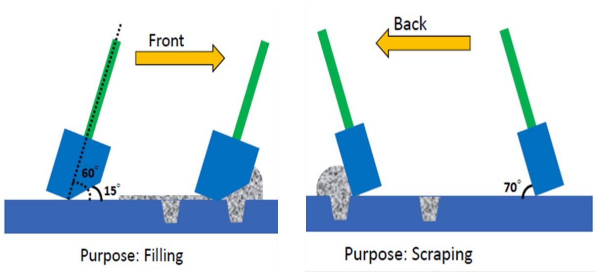



**Figure 5. Conductive Paste Via-filling process**

Different types of paste were tried out for manual printing experimental process then processed through respective curing conditions and descum process, depicted in Table.1.

| Items | Sample A | Sample B | Sample C | Sample D |
|---|---|---|---|---|
| Material Type | Nano Silver conductive paste | Sliver coated Copper Paste | | Silver Paste |
| Filler (um) | N.A | 3-5 | 3-8 | < 45 |
| Curing Condition | Room temp | 180°C 60min | 90°C 30min 160°C 60 min | 150°C 60 mins |
| Density [g/cm$^3$] | 1.9 | 4.3 | 5.3 | 4.6 |
| Volume Resistivity [Ω/cm] | - | $2.0 \times 10^{-4}$ | $5.0 \times 10^{-5}$ | $4.0 \times 10^{-4}$ |
| Thermal conductivity [W/m*K] | - | 8 | 40 | 29 |
| Glass transition Temp | - | 200 °C | 56 °C | ≥ 80 °C |

**Table.1 Different types of conductive paste for the experimental development**

Due to rapid dry effect of Sample A, the manual printing process was difficult to conduct and was incomplete. Sample D observed to be oxidised after the plasma descum while Sample B and Sample C completed the paste printing process. Both paste printing methods, vacuum printing and manual printing, were tried out with Sample B and Samples C for via-filling process. Defective paste printing effect could be observed during the paste printing process, when the squeegee returned to scrape off the excessive paste, the paste printed into the via stick back onto the squeegee, leaving a hole near the edge of the via, as shown in Figure 6. Figure 7(a) depicts the cross-sectional view of an incomplete via-fill while Figure 7(b) illustrates the incomplete via-fill reflected through X-ray analysis.

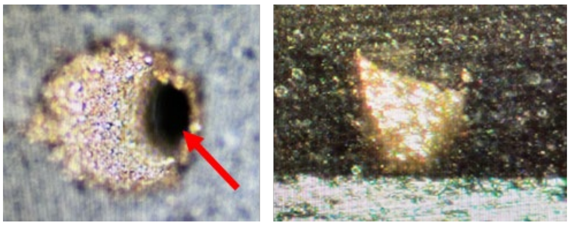


**Figure 6. Incomplete via-filling and cross-sectional of TMI after curing**

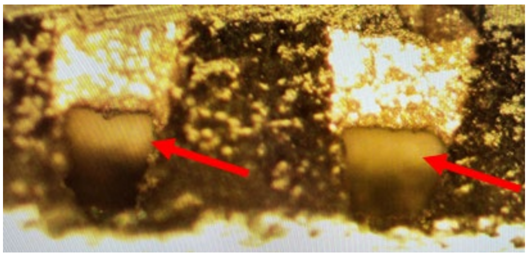


**Figure 7(a). Cross-sectional view of Incomplete via-filling TMI after curing**

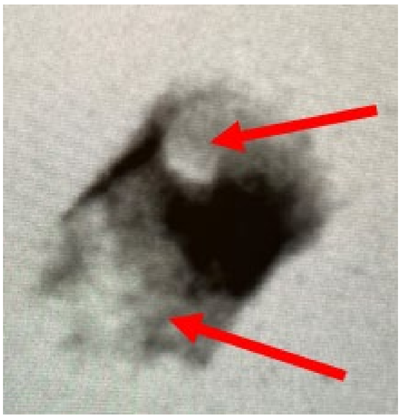


**Figure 7(b). Tilted X-ray analysis of incomplete via-fill**

The paste printing via-filling method was improvised using the selected pastes; Sample B and Sample C, with small filler size ranging from 3um to 8um. These two paste materials offer a contrast in thermal conductivity, the rate at which heat is transferred by conduction through a cross-sectional area of the material, stated at 8 W/m.K and 40 W/m.K respectively. The glass transition temperature between the two paste types differs about 150$^{\circ}$C, with volume resistivity or specific electrical resistance, stated at $2.0X10^{-4}$ (Ω.cm) and $5.0X10^{-5}$ (Ω.cm). The test vehicle with the conductive paste is sent for Curing after completing the via-filling process. At post-Curing, the conductive paste observed to reduced below the printed surface and resulted to a dishing effect, 60um below the printed surface. The via-filling approach formed interlocking effect between the conductive paste against the granular-coarse sidewall of the laser-drilled vias, as depicts in Figure 8(a) Cross-sectional of filled-vias with conductive paste. Figure 8(b) Tilted X-ray image of filled-vias.

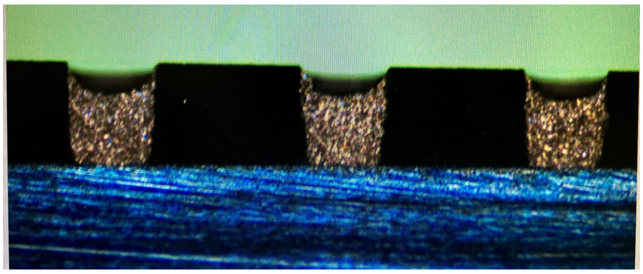
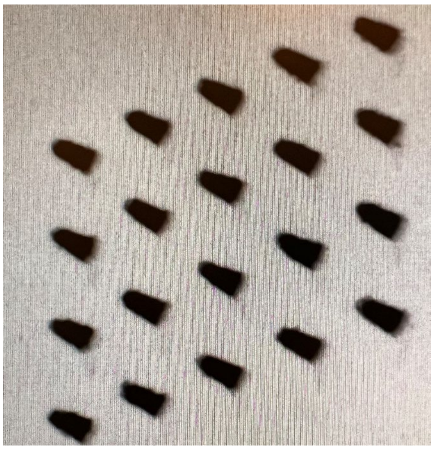


**Figure 8(a) Cross-sectional of filled-vias with conductive paste**



**(b) Tilted X-ray image of filled-vias**

**Figure 8(a) Cross-sectional of filled-vias with conductive paste. Figure 8(b) Tilted X-ray image of filled-vias.**

Laser drilled vias provide versatility in forming Through-mold Interconnects. Laser drilled vias can be applicable to both Mold-First and RDL-First for FOWLP [1], [2]. In prior Through- Mold Interconnects (TMI) developments, the interconnection formations were restricted to copper pillars and via electro-plating. Conductive paste via-filling implementation could be an alternative method for TMI for laser drilled vias to overcome the inconsistent and non-uniformity granular-coarse via surface that could arise poor continuity when electro-plating was used. Conductive paste via-filling is an approach that can be implemented at ease, in comparison to the prior method of forming thick copper seed through the sputtering process and electro-plating copper into the via to compromise the non-uniformity of the sidewalls. The conductive paste via-filling process has an advantage over the electro-plating method, in forming the interconnection through the laser drilled vias. The interlocking feature is formed between the fillers present in the paste against the drilled sidewall of the TMV. The conductive paste could be a more economical solution with shorter cycle time in forming the TMI between the embedded connections to the topside of the package. Amongst the comparison between the TMIs, the via-filling approach will be an economical and productive method to implement for laser drilled vias. The Vertical Wire-bonding method though gain advantage due to its attainable high aspect ratio but can only be applicable to RDL-First process and probable to wire sweep during molding process, due to the small diameter. [1], [4] Thus, the conductive via-filling will be an alternative method to include in the TMI continuous development to provide solution to more applications.

**Conclusion**

Via-filling with conductive paste, in comparison to the other developed TMI formation methods, is simpler and more economical to implement. The silver coated copper paste observed to be a better candidate for via-filling than silver-epoxy paste. It enables an electrical interconnect between the embedded RDLs to the external connections of the package, through the conductive paste filled vias. It eliminates supplementary processes to form electrical interconnections from within the package to exterior of the package.

**Acknowledgement**

This research was supported by the Agency for Science, Technology and Research (A*STAR) under Centre of Excellence in Advanced Packaging 3.0 (Grant No I2101E0008).

We would like to express our gratitude to Susumu Chiba and Miyamoto from Tatsuta Electrical and Cable on their support and other material suppliers who contributed to this development. We would also like express our gratitude to IME-MDRA; Ms. Michelle Chew B.R and Mr. Calvin Chua H.M for their support on electrical and cross-sectional results.

**References**

[1] S. W. Ho *et al.*, "Through mold interconnects for fan-out wafer level package," *2016 IEEE 18th Electronics Packaging Technology Conference (EPTC)*, Singapore, 2016, pp. 51-56, doi: 10.1109/EPTC.2016.7861441.

[2] S. W. Ho *et al.*, "Development of FO-WLP Package-on-Package using RDL-first Integration Flow," *2018 IEEE 20th Electronics Packaging Technology Conference (EPTC)*, Singapore, 2018, pp. 612-617, doi: 10.1109/EPTC.2018.8654431.

[3] Thomas J.Colosimo, JR., and Jon W.Brunner, "Methods of Forming Wire Interconnect Structure", U.S Patent 2015/0132888 A1, issued date May 14, 2015

[4] B. Buckalew, T. Ponnuswamy, S. Mayer, K. Thorkelsson, J. Oberst and G. Graham, "Within-feature-shape (WiF) control of mega pillars for high density fan-out (HDFO) technology," *2016 IEEE 18th Electronics Packaging Technology Conference (EPTC)*, Singapore, 2016, pp. 808-812, doi: 10.1109/EPTC.2016.7861592.