SPIL Property

Mechanical and Thermal Performance of CoWoS-S Using Glass-Core Substrate and Glass-Interposer

Shane Lin*, Vito Lin, Andrew Kang, D.S. Jiang
Siliconware Precision Industries Co., Ltd. (SPIL)
No. 153, Sec. 3, Chung Shan Rd., Tantzu
Taichung, Taiwan
Ph: 886-4-2534-1525 Ext 7928; Fax: 886-4-2535-5033
Email: shanelin1@spil.com.tw

Abstract

With the rise of the high-speed computing era and Artificial Intelligence (AI), Chip on Wafer on Substrate (CoWoS) package has become a mainstream package type. CoWoS-S (Si-interposer), with its high interconnection density and heterogeneous integration capabilities, is now the dominant CoWoS product on the market. However, as package size increase, the drawbacks of CoWoS-S have also emerged, such as high manufacturing cost of silicon interposers and the large stress and high warpage resulting from large reticle size. Glass interposer and glass-core substrate are currently seen as a solution to these problems, due to their lower cost compared to silicon and their excellent coefficient of thermal expansion (CTE) adjustability. Therefore, this study explores the thermal stress, warpage and thermal performance of glass applied to interposer and substrate core, and compares them with normal CoWoS-S.

This paper utilizes the finite element analysis software ANSYS to conduct simulations. First, the stress and warpage performance of CoWoS-S using a glass substrate versus a conventional organic substrate were compared. Under the same thickness, the glass substrate exhibited lower warpage but higher stress at the chip module (CM) corner. However, by reducing the glass substrate thickness to match the warpage of organic substrate, the glass substate demonstrated better stress performance. Furthermore, the stress and warpage behavior of a glass interposer versus a conventional silicon interposer were investigated. The results showed that the glass interposer performed better in both warpage and stress. When the silicon interposer size was fixed at 3.3X the reticle size, a glass interposer size of 5.2X yielded similar stress and warpage performance. This study also explored the thermal behavior of glass interposer and glass-core substrate, revealing that with a strong external cooling system, the difference between glass and initial materials was insignificant. However, as the cooling capability of the external cooling system decreased, the differences became more pronounced.

This research explored the application of glass materials in different package structures through simulation, providing directions for structural improvement and confirming the differences in thermal behavior. Above all, the number of experiments was reduced, and design directions for future CoWoS-S applications using glass materials were provided.

Key words

Chip on Wafer on Substrate (CoWoS), Glass interposer, Glass substrate, Warpage, Thermal, Reliability

I. Introduction

Against the backdrop of the explosive growth in high-performance computing (HPC) and large-scale model training, Chip-on-Wafer-on-Substrate (CoWoS) advanced packaging technology has become the core manufacturing technology for premium AI accelerators, such as those from AMD and NVIDIA, owing to its superior transmission bandwidth and low latency. Among its variants, CoWoS-S (Silicon Interposer), which features a full-silicon interposer design, delivers superior performance compared to its counterparts, CoWoS-R (RDL Interposer) and CoWoS-L (Local Silicon Interconnect, LSI). With the recent trend

toward expanding package sizes, the embedded chip module (CM) is evolving from the current 3.3x reticle size to 4 to 5 x, and potentially up to approximately 10x. However, the high manufacturing costs and brittle nature of large-scale interposer designs have increasingly amplified yield loss issues. Consequently, enhancing packaging reliability while maintaining high-performance computing capability has emerged as a critical research issue.

Glass interposers are widely regarded as a promising solution to the aforementioned challenges. Beyond their excellent compatibility with panel-level processing, which facilitates cost reduction [1], the defining advantage lies in the tunability of the coefficient of thermal expansion (CTE) of glass, enabling exceptional thermal matching with organic substrates. Previously, the pronounced CTE mismatch between the silicon interposer and the underlying organic substrate frequently induced significant stress concentrations at the corners of the silicon interposer, resulting in structural cracking. By adjusting the CTE of the glass interposer to closely match that of the organic substrate, reliability failures caused by severe stress can be effectively mitigated, while simultaneously yielding superior warpage performance; nevertheless, challenges such as via cracking remain to be addressed [2].

In addition to its application in interposers, glass can serve as a substitute for the core material of substrates [3]. The aforementioned high CTE tunability can further alleviate the CTE mismatch effect between the chip module (CM) and the substrate, thereby reducing the overall package warpage and suppressing stress concentration at the interposer corners. Furthermore, related studies have indicated that introducing a resin layer between the glass core and the copper layer can act as a buffer to absorb mechanical stress[4].

Apart from warpage and mechanical stress performance, given the demanding thermal dissipation requirements of high-wattage CoWoS packages, the thermal behavior of both the glass interposer and the glass core must be evaluated concurrently. This evaluation is essential to achieve a comprehensive, global understanding of the combined impact resulting from the adoption of glass materials.

In summary, this study adopts glass as both the interposer and core material for a CoWoS-S test vehicle (TV). Finite element analysis (FEA) simulations are conducted using ANSYS software to compare its warpage and stress characteristics with those of conventional interposers and substrates. Finally, thermal simulations are performed using the computational fluid dynamics (CFD) software, FloTHERM, to compare the discrepancies in thermal dissipation performance at the system level.

II. TV and Modeling

A. Test Vehicle (TV)

The TV adopted in this study is a CoWoS-S package with a package size of 60 mm x 77 mm and a CM size of 50 mm x 58 mm, which corresponds to approximately 3.3x the reticle size. A forged-type heat sink design is utilized for warpage controlling. The CM features a homogeneous structure, wherein one larger die is surrounded by ten smaller dies, as illustrated in Fig. 1. The spacing between adjacent dies is 100 um, which is entirely filled with underfill material. The substrate comprises 20 copper layers with a core thickness of 1240 um. The overall structural configuration is depicted in Fig. 2.

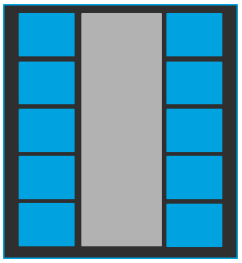

Fig 1. CM floorplan

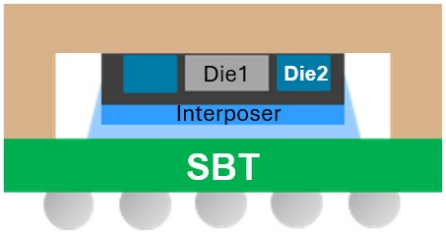

Fig 2. Overall structural configuration

B. Loading & Boundary Conditions

Regarding the warpage analysis, two results are presented: room temperature (RT) and high temperature (HT). The loading condition for RT involves a temperature decrease from the curing temperature of the underfill at the bottom of the CM to 25°C, whereas the condition for HT involves a temperature increase from the curing temperature to 260°C. For stress analysis, the reliability performance under thermal cycling (TC) conditions is simulated, where the stress behavior is observed during a temperature drop from 125°C to 25°C. The boundary conditions are three point constraint.

For the thermal simulation, the total input power is specified as 300 W, and an external liquid-cooling system is configured above the package heat sink, as depicted in Fig. 3.

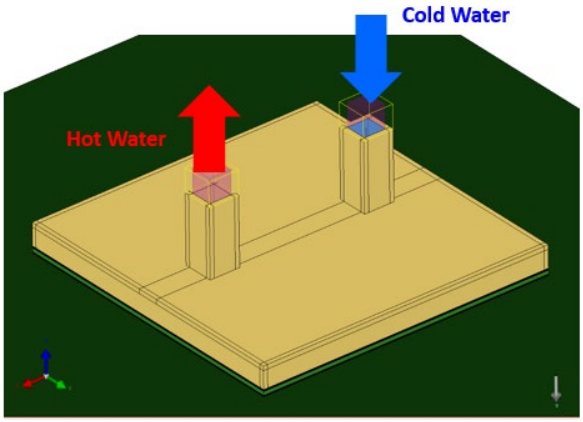

Fig 3. Thermal system[5]

C. *Simulation DOE*

First, the evaluation of the glass interposer was conducted by comparing the warpage and stress performances of the glass interposer and the silicon interposer under identical geometric configurations. The CTE of silicon and glass are 2.8 ppm/°C and 9.0 ppm/°C, respectively, while the effective CTE of the substrate is approximately 14 ppm/°C. Furthermore, this study scaled up the CM reticle size to evaluate the maximum allowable dimensions achievable by implementing the glass interposer while maintaining equivalent warpage and stress performances, as listed in Table I.

Table I. Glass-interposer DOE

DOE	CM reticle ratio	CTE (ppm/°C)	
		Interposer	Substrate
POR	3.3x	2.8	14
Leg1	3.3x	9.0	
Leg2	Simulation define	9.0	

Subsequently, the research focused on the glass substrate to investigate the discrepancies in warpage and stress between the glass core and the organic core under a fixed core thickness, wherein the CTE of the organic core and glass core are 6.2 ppm/°C and 3.8 ppm/°C for this simulation, respectively. Following this, a thickness reduction analysis was performed on the glass core to determine the minimum thickness required for the glass core to exhibit warpage mitigation capabilities comparable to those of a thicker organic core, while simultaneously evaluating the trend of stress variations, as outlined in Table II.

Table II. Glass-core DOE

DOE	Core thk (um)	Core CTE (ppm/°C)	
		Organic	Glass
POR	1240	6.2	--
Leg3	1240	--	3.8
Leg4	Simulation define	--	3.8

Finally, thermal simulations were carried out to evaluate the individual impacts of implementing the glass interposer alone and the glass core alone. Moreover, the performance discrepancies regarding the cooling capability of different liquid-cooling systems were systematically compared in Table III.

Table III. Thermal simulation DOE

DOE	Cooling capability	Material	
		Interposer	Core
POR	Powerful	Silicon	Organic
Leg1		Glass	Organic
Leg3		Silicon	Glass
Leg5	Powerless	Silicon	Organic
Leg6		Glass	Organic
Leg7		Silicon	Glass

III. Results Analysis

A. *Warpage & Reliability*

The simulation results comparing different interposer materials under identical geometric structures are listed in Table IV. Compared to the silicon interposer, implementing the glass interposer yields superior performance in both warpage and stress. Specifically, the warpage at RT and HT exhibits improvement margins of approximately 22% and 36%, respectively. Regarding the mechanical stress, two distinct stresses were evaluated and compared: the stress at the interposer corner and the stress at the silicon die corner. The results indicate that the corresponding stress reductions are 21% and 19%, respectively. This enhancement is attributed to the reduced coefficient of CTE mismatch between the substrate and the CM containing the glass

interposer.

Additionally, this study revealed that while retaining the baseline warpage and stress levels, the package size could be scaled up from 60 mm x 77 mm to 65 mm x 97 mm. Concurrently, the CM size could be expanded from the original 50 mm x 58 mm (3.3x reticle size) to 58 mm x 78 mm (5.2x reticle size), as illustrated in Fig. 4. This finding implies that by implementing a glass interposer, the CM design can accommodate more intricate configurations, thereby further enhancing the overall packaging performance.

Table IV. Glass-interposer results

DOE	CM reticle ratio	Warpage (um)		Corner stress ratio	
		RT	HT	Interposer	die
POR	3.3x	351	182	1.00X	1.00Y
Leg1		274	116	0.79X	0.81Y
Leg2	**5.2x**	355	184	0.99X	0.99Y

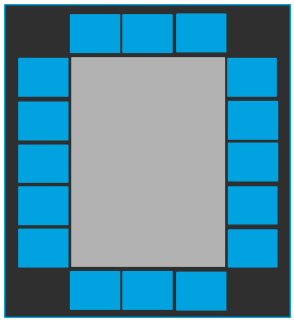

Fig 4. 5.2x reticle size CM

Table V presents the simulation results for the glass core. The results indicate that under an identical core thickness, although the glass core exhibits lower warpage performance, it induces greater stress at the corners of the silicon interposer. This phenomenon is attributed to the higher Young's modulus of glass compared to conventional organic materials. Consequently, while warpage is suppressed, the deformation of the internal structure is constrained, despite the lower CTE mismatch between the glass core and the CM. In contrast to the glass interposer, the glass core exhibits an opposite trend regarding the stress at the interposer corners. This discrepancy arises because the glass interposer replaces silicon, which possesses a higher Young's modulus, whereas the glass core replaces the organic material characterized by a lower Young's modulus. Furthermore, because the glass core occupies a larger volume, the influence of its Young's modulus is more pronounced than that of its CTE. The comparison of material properties is summarized in Table VI.

Extending the aforementioned findings, the simulation results reveal that if the thickness of the glass core is reduced to achieve a warpage performance comparable to that of the conventional organic substrate, the glass core subsequently yields superior stress performance, as outlined in Table VII below.

Table V. Glass-core results

DOE	Core thk (um)	Warpage (um)		Corner stress ratio
		RT	HT	Interposer
POR	1240	351	182	1.00X
Leg3		295	134	1.12X

Table VI. Comparison of material properties

Material	Glass	Silicon	Organic core
Young's modulus (GPa)	80	160	32

Table VII. Thinner glass core results

DOE	Core thk (um)	Warpage (um)		Corner stress ratio
		RT	HT	Interposer
POR	1240	351	182	1.00X
Leg4	630	353	185	0.93X

B. Thermal

The thermal simulation results are presented in Table VIII. The results indicate that under a powerful system cooling device [5], no significant discrepancy is observed, regardless of whether the glass interposer or the glass core is implemented. This phenomenon occurs because more than 95% of the heat is dissipated through the upward thermal path, and the heat sources are located above the interposer and the core; consequently, the peak temperatures of the dies remain virtually identical, as illustrated in Fig. 5. However, under a powerless system cooling device, the thermal performance of the glass interposer is paradoxically inferior to that of the silicon interposer. This degradation arises because approximately 50% of the heat is dissipated downward through the PCB, whereas the thermal conductivity of glass is not as superior as that of silicon. Conversely, the performance of the glass core is slightly superior to that of the organic core, which is attributed to the

higher thermal conductivity of glass. The corresponding material properties are summarized in Table IX.

Table VIII. Thermal results

DOE	Cooling capability	MAX junction temp (°C)
POR	Powerful	79.9
Leg1		80.1
Leg3		78.7
Leg5	Powerless	125.8
Leg6		142.3
Leg7		119.3

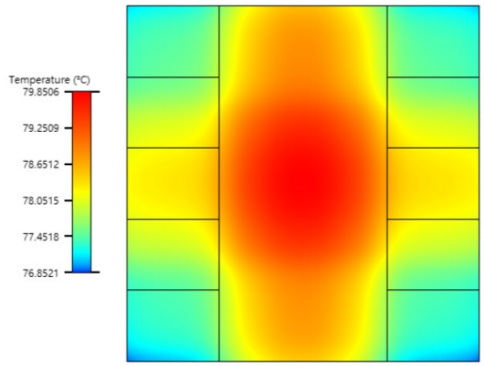

Fig 5. Temperature contour

Table IX. Material properties

Material	Glass	Silicon	Organic core
Thermal conductivity (W/mK)	1.5	150	0.8

IV. Conclusion

This study investigated the mechanical performance and thermal behavior of glass interposers and glass core substrates, respectively. The results indicate that the glass interposer yields superior warpage and stress performances compared to the silicon interposer. Furthermore, a CM with a size of 5.2x reticle utilizing a glass interposer exhibits mechanical performance comparable to that of a 3.3x reticle size CM utilizing a silicon interposer. Conversely, although the glass core delivers enhanced warpage mitigation performance, its stress performance is inferior to that of the conventional organic core; nevertheless, the induced stress can be effectively alleviated by reducing the thickness of the glass core. Regarding the thermal behavior, when coupled with a powerful thermal management system, both the glass interposer and the glass core exhibit performance virtually identical to that of conventional materials. However, under a powerless cooling system, the thermal behavior of the glass interposer degrades, whereas the glass core paradoxically demonstrates improved performance.

Although numerous manufacturing and processing challenges remain to be overcome for glass interposers and cores, their superior mechanical characteristics ensure that this technology will inevitably play a pivotal role in the future of semiconductor packaging.

References

[1] Terry Wang, C. Y. Chang, William Yang, Y. J. Yang, P. P. Cheng, C. M. Tseng, H. Y. Wu, Austin Cheng, H. Y. Huang, Meiten Koh, C. H. Huang, Kent Chen "Panel Level Interposer by Using Glass Carrier for 2.5D Advance IC Package Application", 2025 IEEE 75th Electronic Components and Technology Conference (ECTC), USA, pp. 793-797.

[2] J. C. Chuang, C. C. Lee, W. C. Tsai, H. Z. Lin, C. T. Yang, C. I. Li, S. H. Lee, S. H. Kuo, "Physics-based Modeling with Nanoindentation on the Mechanical Reliability of TGV Substrates Under Annealing Effects", 2025 IEEE 75th Electronic Components and Technology Conference (ECTC), USA, pp. 985-989.

[3] John. H. Lau, Ning Liu, Mike Ma, T. J. Tseng, "Glass-Core Substrate versus Organic-Core Substrate", 2025 IEEE 75th Electronic Components and Technology Conference (ECTC), USA, pp. 1014-1020.

[4] Koji Fujimoto, Takahiro Tai, Satoru Kuramochi, "Development of Glass Core Substrates for Long-Term Reliability Under Thermal Stress", 2025 IEEE 75th Electronic Components and Technology Conference (ECTC), USA, pp. 995-999.

[5] Shane Lin, Vito Lin, Andrew Kang, Y. P. Wang, "Thermal Performance of High Thermal Conductivity TIM for Large Advanced Package through TTV Measurement and FEM Analysis Approach", 2025 58th International Microelectronics Assembly and Packaging Society (IMAPS), USA.