

Pressure Assisted Vs Pressureless Silver Sintering

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Abstract

Silver sintering is as a method for die attach which is used for high-power and high-frequency microelectronic devices. Silver's material properties make it a viable material for performance in extreme applications. As device integration scales the choice between pressure assisted and pressureless sintering becomes critical. The pressure assisted processes allows for dense, uniform bondlines with low voiding and enhanced mechanical strength. Pressureless sintering reduces stress on fragile components and simplifies the die bonding process design resulting in compatibility across a wider range of packages. By comparing bondline morphology, thermal impedance, and die shear strength between both approaches the trade-offs become apparent with respect to performance and reliability. Additionally, by doing analysis using various characterization techniques it becomes clear that process conditions have a strong impact on joint quality. This will help guide sintering process choices based on device needs and production goals supporting the use of silver sintering in power, RF, and photonic packages.

Introduction

Pressureless silver sintering is a die attach method that enables the formation of conductive and thermally stable bonds. It

mostly utilizes silver nanoparticle paste which has material properties that support densification and solid state bonding. The process is done by using a sintering furnace. It promotes diffusion driven necking between silver particles through thermal energy alone. Pressureless sintering is especially useful for attaching sensitive dies or components that could be damaged by mechanical pressure.

The pressure assisted sintering process is similar to the pressureless approach except for one key difference. During the thermal cycling phase a controlled force between 5 and 30 MPa is applied to enhance contact between the silver particles and the substrate [1]. This applied pressure reduces void formation which in turn increases bond density. Pressure assisted sintering is mostly used in high reliability applications where strong mechanical performance and minimal defects are critical.

Process and Mechanisms

Pressureless sintering is a die attach method which forms bonds through thermal activation without applying mechanical pressure. The process typically uses a reflow oven or sintering furnace capable of maintaining stable temperatures between 200°C and 300°C. These systems must have controlled ramp and dwell profiles to ensure uniform thermal distribution and organic

burnout. An inert atmosphere such as nitrogen or forming gas is usually required to prevent oxidation. In lower volume applications or research settings, hot plates under a controlled environment can also be used. The material normally used in the paste formulations for pressurless sintering is silver. They are typically nanoparticle based and engineered for low temperature activation. These pastes rely on enhanced surface diffusion and contain organic binders that decompose cleanly without leaving residue. Brands such as Heraeus and Kyocera offer formulations optimized for the pressure less silver sintering process.

The process begins by applying a silver paste onto the substrate using stencil printing or automated dispensing. After applying the paste, the die is placed with minimal pressure onto the wet bond line. Then a pre drying stage is carried out at approximately 80°C to 120°C to evaporate solvents and prevent paste slumping. After the pre drying stage, the assembly is transferred into a reflow oven or furnace where it is heated to the sintering temperature and held for 30 to 60 minutes. During this period, organic components burn off and the silver particles undergo densification through diffusion-driven necking. After sintering, the assembly is gradually cooled to avoid inducing stress. The resulting bond is porous but stable and provides adequate thermal and electrical performance for applications involving sensitive dies or components that cannot withstand high mechanical loads.

Pressureless silver sintering is mostly used for photonic and MEMS packaging where minimal stress and placement accuracy are crucial. [2-4]

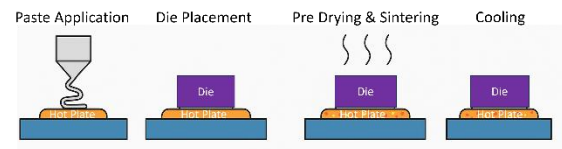


Figure 1: Process flow for pressureless silver sintering using a sintering oven, (1) including paste application, (2) die placement, (3) pre-drying, and sintering, (4) and finally cooling.

Pressure assisted silver sintering has a similar process structure when compared to pressureless silver sintering, but there is one key difference which includes applying a controlled mechanical load during the thermal cycle. This pressure allows for a better bond formation between the silver particles and the substrate. This promotes more effective diffusion and reduced void formation. The tools required for this method include a sintering press, thermocompression bonders, or hot press systems. This tool must be able to provide precise temperature control, within a similar range to that of the pressureless sintering ovens. It should also be able to apply uniform force between 1 MPa and 30 MPa across the die's area. Additionally, the tool must have the capabilities to enable a inert or vacuum atmosphere to prevent oxidation and maintain a planarity tolerance within ± 15 microns to ensure even bonding. Fine pitch hybrid bonders and thermal compression systems from manufacturers

such as Finetech are commonly used in high-precision settings [5].

Both nanoparticle and micron-scale formulations are compatible silver pastes for pressure assisted sintering. The use of pressure allows the process developers to utilize pastes with lower sinter ability. This allows for the development of thicker bondlines and higher thermal conductance. Products such as Indium Corporation's Heat-Spring and Alpha's sinter able silver pastes are commonly employed in this method [7]. The process steps mirror those of pressureless sintering in the early stages, starting with paste application and die placement followed by a low-temperature pre-drying stage. The key difference is during the sintering step. The die is subjected to mechanical pressure while the system is heated to the target temperature. This combined thermal and mechanical input promotes particle deformation, accelerates grain growth, and enhances bond integrity. The cooling stage may occur under load or after a controlled pressure release to avoid stress induced defects. This method results in dense, low-void bond lines with superior mechanical and thermal performance. It is widely used in power modules, automotive electronics, and aerospace systems where long-term reliability and thermal management are critical [1,5]

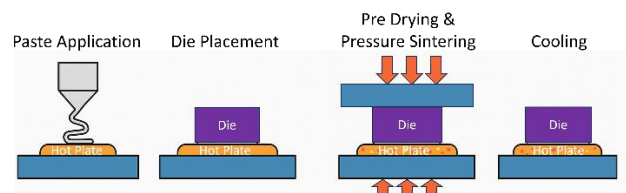


Figure 2: Schematic illustration of the pressure-assisted sintering process. (1) Dispensing of silver paste (2) Die placement, (3) Simultaneous application of heat and pressure to promote densification and reduce porosity, (4) and finally cooling

Mechanical Performance

By comparing the die shear test results of both pressure less and pressure assisted sintering it becomes apparent which technique would result in a stronger die bond. These results could also help understand the void concentration between methods as an increased percentage of voids correlates to a decreased die shear strength.

In order to make this comparison, It's best to access the shear strength of dies which are sintered using the same silver paste. Below is a figure from an article by Dr. Liu and his collaborators [8] as well as an article by Dr. Chen and his collaborators [9] which depicts the shear strength of a die after it has undergone pressure assisted and pressureless sintering respectively.

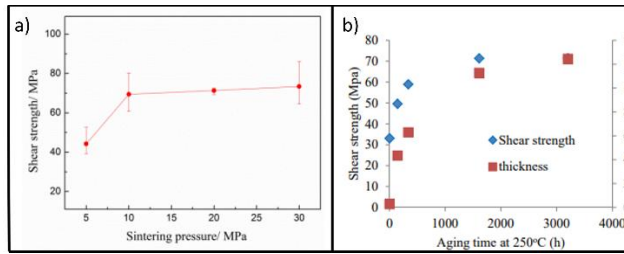


Figure 3: Shear strength of silver sintered die bonds under (a) pressure assisted [8] and (b) pressureless conditions [9].

Figure 3a shows the die shear results from the pressure assisted technique as the sintering pressure is increased. The graph shows that shear strength increases significantly between 5 MPa and 15 MPa of applied pressure. At 5 MPa, the average shear strength is around 45 MPa. When pressure is increased to 15 MPa, the shear strength jumps to approximately 75 MPa, indicating that initial pressure has a strong influence on bond integrity. Beyond 15 MPa, there is little additional gain in strength, suggesting a saturation point where further pressure yields diminishing returns.

Figure 3b shows the effect of isothermal aging at 250°C of pressureless silver sintering over a duration of up to 3,500 hours. The shear strength begins at around 25 MPa and gradually increases to approximately 70 MPa after 2,000 hours, maintaining that level through extended aging. Alongside this, the dense layer thickness increases from about 2 μm to over 12 μm, indicating continued densification over time.

These results show that pressureless sintering could achieve a shear strength similar to the pressure assisted technique,

but only after long periods of thermal aging. Shear strength increases steadily from about 25 MPa to nearly 70 MPa over 2,000 hours which suggests that the bond forms gradually through slow particle diffusion and densification. The growth in dense layer thickness from around 2 microns to over 12 microns supports this conclusion. It shows that the material continues to consolidate with time. While the final bond strength is comparable to that of pressure assisted sintering, the long processing time makes it less practical for fast paced manufacturing. Pressureless sintering is better suited for use cases where pressure must be avoided and where the thermal properties of a material allows for longer cycles.

Morphological and Structural Analysis

To assess the structural integrity of silver sintered bonds, researchers use several characterization techniques to analyze key features such as void content, particle connectivity, and interface quality. One of the most common tools for this purpose is Scanning Electron Microscopy (SEM), which provides high resolution images of both surface and cross sectional morphology. These images reveal important details including grain structure, crack formation, and porosity. Voiding, which refers to the formation of gaps or air pockets within the bondline, is directly measured through porosity percentage. A higher porosity indicates a greater amount of voiding, which negatively affects both the

mechanical strength and thermal performance of the joint.

Through SEM characterization of the pressureless sintering case Dr. Chen and their collaborators were able to determine the porosity at center and edge areas for samples aged at different times [9].

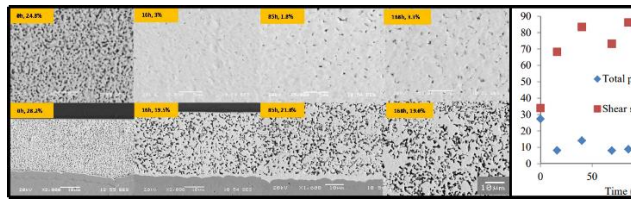


Figure 4: (Left) SEM cross sectional images showing bondline porosity under varying sintering times for the center (upper row) and the edge (lower row). (Right) shows the porosity percentage and shear strength data for various sintering times in hours. [9]

By analyzing the porosity percentage it becomes clear that a prolonged period of sintering time reduces the porosity. This correlation is evident when comparing the 0 hour pressureless sintering to the 16 hour duration, as porosity decreases from 24.8% to 3% at the center of the bond.

To compare the porosity percentages between pressure-assisted and pressureless sintering, the study by Dr. Yang and collaborators [8] is referenced, as it provides SEM cross sectional images of the bond center following sintering under varying applied pressures. Shown below is an SEM image alongside a schematic outlining the porosity calculation process, and a graph demonstrating the correlation between applied pressure and porosity percentage.

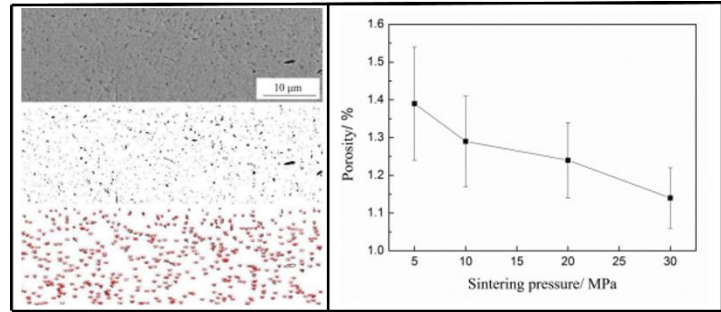


Figure 5: (Left) SEM image with post-processing schematic for porosity calculation. (Right) Graph showing porosity percentage versus applied sintering pressure. [8]

In Figure 3, the graph showing porosity percentage for pressure-assisted sintering indicates that at 5 MPa, the porosity is approximately 1.4%. When the applied pressure is increased to 30 MPa, the porosity decreases slightly to around 1.1%.

This shows that even large increases in sintering pressure can result in denser bondlines, though the rate of improvement diminishes at higher pressures. These findings reinforce the role of applied pressure in enhancing microstructural uniformity which in turn reduces void content within the sintered joint.

When comparing the results of pressureless and pressure-assisted silver sintering, a clear distinction in bondline quality emerges. In the pressureless case studied by Dr. Chen and collaborators [9], porosity at the center of the bond was initially measured at 24.8% but decreased significantly to 3% after 16 hours, and 1.8% after 85 hours of sintering at 250°C. This indicates that extended thermal exposure can improve densification over time, though the initial porosity remains relatively high.

In contrast, the pressure assisted case examined by Dr. Liu and collaborators [8] shows that implementing low pressures such as 5 MPa while sintering leads to a reduced porosity of approximately 1.4%. These results suggest that pressure-assisted sintering is more effective in achieving low void, high-density bonds within a much shorter processing time. While prolonged aging in pressureless sintering can improve microstructure, the application of pressure during sintering provides a more immediate and consistent reduction in porosity.

While pressure assisted sintering offers faster densification and slightly lower porosity, pressureless sintering is still incredibly important particularly for components that cannot tolerate mechanical stress during bonding. In the study by Dr. Chen and collaborators [9], extended aging at elevated temperatures allowed pressureless sintered joints to achieve porosity levels as low as 1.8%, which is comparable to the 1.1–1.4% range observed in pressure-assisted cases reported by Dr. Liu and collaborators [8]. Although pressure assisted sintering achieves these results quickly, the difference in final void content is relatively small. For delicate dies or photonic components where even minimal pressure could damage alignment or surface integrity, pressureless sintering offers a safer and more compatible approach. With optimized thermal profiles and sinterable pastes, pressureless sintering can yield reliable, low void bonds without

compromising the mechanical or structural integrity of fragile devices.

Summary

Pressure assisted silver sintering achieves low porosity and high mechanical strength through the application of moderate pressure during thermal processing. Even at pressures as low as 5 MPa, bondline voiding is significantly reduced, and shear strength improves rapidly with increasing pressure up to 30 MPa. This method is best suited for high reliability applications such as power modules and automotive or aerospace systems where thermal and mechanical performance are critical, and the components can tolerate applied force.

Pressureless sintering is capable of achieving comparable porosity and bond strength through extended thermal aging. Porosity levels below 2% and shear strengths exceeding 65 MPa have been demonstrated after sufficient sintering time. This makes pressureless sintering ideal for photonic and MEMS devices where mechanical stress must be avoided. While pressure-assisted sintering offers faster densification, pressureless sintering provides broader compatibility with sensitive die and complex package architectures.

Sources

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