Proceedings of the 4th International Conference on Functional Materials and Civil Engineering
DOI: 10.54254/2755-2721/2026.37704

From Soldering to Sintering: Novel Interconnection Technology for SiC Power Device Package

Jinghan Yuan

Department of Materials Science and Engineering, Southern University of Science and Technology, Shenzhen, China
12412358@mail.sustech.edu.cn

Abstract. As new energy vehicles and wide-bandgap semiconductor power devices have been used more widely, higher requirements have been put forward for packaging interconnections, above all under repeated thermomechanical loading, at high operating temperature, and at high current density. Conventional solder joints do not perform well in such a situation, since intermetallic compounds grow, voids form, and fatigue damage develops during long service, and the long-term reliability is thus weakened; therefore, three typical interconnection technologies of next-generation power devices are reviewed in this paper, that is, transient liquid-phase sintering/bonding, silver sintering, and copper sintering. Their bonding mechanisms, processing characteristics, mechanical properties, electrical and thermal performance, and major challenges are compared. TLPS can achieve low-temperature bonding and high-temperature service, but its reliability is restricted by brittle intermetallic compounds and void evolution. Ag sintering provides excellent thermal conductivity, electrical conductivity, bonding strength, and high-temperature stability, but high cost, electrochemical migration, and large-area bonding remain important concerns. Cu sintering offers low cost, good conductivity, and better resistance to electrochemical migration, while oxidation sensitivity and pressure-dependent densification limit its practical application. Finally, this review suggests that future interconnection design should balance performance, cost, process compatibility, and long-term reliability for high-power semiconductor packaging.

Keywords: Power device packaging, Die attach, Transient liquid-phase sintering, Silver sintering, Copper sintering, Wide-bandgap semiconductor

1. Introduction

With the rapid expansion of the new energy vehicle industry and the increasing deployment of third-generation semiconductor power devices, particularly silicon carbide (SiC) and gallium nitride (GaN), power electronic packaging must operate under increasingly severe thermal, electrical, and mechanical conditions [1]. Compared with conventional silicon devices, wide-bandgap semiconductors can operate at higher voltages and temperatures while offering faster switching speeds and lower conduction losses. These characteristics are attractive for compact traction inverters and high-efficiency power conversion systems. At the package level, however, the harsher

© 2026 The Authors. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).

DOI: 10.54254/2755-2721/2026.37704

operating environment places considerable stress on the interconnection layer. Low electrical resistance and efficient heat dissipation must be maintained without sacrificing mechanical integrity, particularly during prolonged high-temperature operation and repeated thermomechanical cycling [2].

Environmental regulations have narrowed the use of lead-containing solders step by step, and lead-free solders have therefore become the common option in many electronic packaging applications. Among these lead-free materials, Sn-based solders are still mainly used to attach the die and to form the electrical interconnection; their processing technology is mature and their manufacturing cost is relatively low. Their suitability for SiC and GaN power modules is nevertheless limited by temperature. Most conventional Sn-based joints are intended for service below approximately 200 °C, whereas the junction temperature of wide-bandgap power devices can approach or even exceed 300 °C [3]. Temperature is not the only concern. The relatively narrow processing window of solder joints, together with interfacial reactions and void formation, can introduce substantial variation in joint quality. During long-term service, thermal-expansion mismatch among the semiconductor chip, metallization layers, substrate, and encapsulation materials repeatedly loads the interconnection. Crack initiation, intermetallic compound growth, creep deformation, and fatigue damage may therefore accumulate over time, gradually degrading the mechanical integrity of the joint and, ultimately, the reliability of the package. For this reason, conventional solder interconnections become increasingly difficult to use when both high-temperature capability and long service life are required.

The temperature limitations of conventional solders have encouraged the development of interconnection technologies that can be processed at relatively low temperatures but remain stable during high-temperature service [4]. Transient liquid-phase sintering/bonding (TLPS), low-temperature Ag sintering, and low-temperature Cu sintering have been studied most widely among these technologies. The bonding mechanisms of the three are quite different, but they all aim at joints which can keep their structure and function above the temperature range that conventional solders can reach. Higher service temperature, better heat conduction, and stronger resistance to thermomechanical degradation are their possible advantages; thus, they are of special value for wide-bandgap power device packaging. This is particularly important in automotive power modules, where high power density, repeated thermal cycling, vibration, and long service life require stable interconnect performance. Considerable progress has already been achieved in the development of these emerging materials. For example, Wu et al. (2021) developed a modified nanosilver paste that could be pressurelessly sintered at 250 °C. The resulting joints exhibited shear strengths exceeding 70 MPa for small bonding areas, while the shear strength of large-area joints remained above 20 MPa [5]. These results indicate that appropriately designed nanosilver pastes can provide both high bonding strength and a certain degree of process flexibility, thereby demonstrating strong potential for power device die attachment. Similarly, Zuo et al. achieved rapid pressureless sintering of copper nanoparticles through an in situ reduction strategy. The resulting Cu joints exhibited high bonding strength and showed considerable potential for the reliable packaging of large-area power semiconductor chips [6]. Such studies demonstrate that advanced interconnect materials can potentially overcome some of the temperature and reliability limitations associated with conventional solder-based joining technologies. Despite the rapid development of these technologies, a unified framework for evaluating advanced interconnect materials should be discussed. Reported studies differ considerably in bonding temperature, pressure, atmosphere, holding time, specimen size, metallization structure, joint thickness, and testing methodology. As a result, directly comparing reported shear strength, thermal conductivity, electrical resistivity, fatigue

DOI: 10.54254/2755-2721/2026.37704

life, or high-temperature stability can be misleading. Good performance of a material in small-area, pressure-assisted laboratory tests does not mean that the same advantages will be kept in industrial processing over large areas and without pressure. Therefore, a systematic comparison should cover the intrinsic material properties together with cost, oxidation sensitivity, scalability, interfacial stability, process compatibility, and reliability under application-relevant conditions.

This review first outlines the technical requirements of power electronic packaging in the context of the rapid development of new energy vehicles and third-generation semiconductor devices, while also discussing the limitations of conventional solders and the current research status of emerging interconnect materials. It then introduces the working principles and processing characteristics of representative interconnection technologies, including transient liquid-phase sintering/bonding (TLPS), low-temperature silver sintering, and low-temperature copper sintering. Subsequently, these materials are comparatively evaluated in terms of mechanical strength, high-temperature stability, process compatibility, and cost. Finally, material-selection recommendations are proposed for different application scenarios, and the future development directions of advanced interconnect technologies are discussed.

2. Representative interconnect technologies

2.1. Transient liquid-phase sintering/bonding materials

Transient liquid-phase sintering or bonding materials generally consist of high-melting-point metal particles and low-melting-point metals or alloys, with Cu-Sn and Cu-In being representative systems. During heating, the low-melting-point component first melts and wets the surfaces of the high-melting-point particles. Subsequent interdiffusion and interfacial reactions generate high-melting-point intermetallic compounds, gradually consuming the liquid phase until it disappears. This mechanism enables bonding at a relatively low temperature while producing a joint capable of stable service at a substantially higher temperature. TLPS therefore offers moderate processing temperatures, reasonable material costs, and good compatibility with existing metallization systems. However, brittle intermetallic phases, residual porosity, incomplete reactions, and reaction-induced volumetric shrinkage may reduce joint toughness and impair reliability under thermal cycling.

2.2. Silver sintering

Silver sintering is based on atomic diffusion, particle-neck formation and growth, pore elimination, and progressive densification under thermal and, in many cases, mechanical loading. The resulting joints exhibit high thermal and electrical conductivity, strong bonding strength, and excellent high-temperature stability. For this reason, silver sintering is currently one of the most mature interconnect technologies for SiC and other wide-bandgap power devices. Its main disadvantages are the high price of silver, the frequent requirement for pressure-assisted processing in large-area bonding, and the risk of electrochemical migration under electrical bias and humid conditions. Manufacturing cost is raised by the above factors, and process integration also becomes more difficult.

2.3. Copper sintering

Copper sintering works in much the same way as silver sintering, and surface diffusion, neck growth, grain-boundary diffusion, and densification all take part in it. Copper offers lower raw-

DOI: 10.54254/2755-2721/2026.37704

material cost, good thermal and electrical conductivity, stronger resistance to electrochemical migration, and excellent compatibility with Cu-based substrates and metallization layers. These characteristics give Cu sintering considerable potential for large-scale and cost-sensitive applications. Its major challenge is the high susceptibility of Cu particles to oxidation. Surface oxides inhibit interparticle diffusion and reduce densification and bonding strength. Therefore, reducing atmospheres, protective coatings, surface activation, or in situ chemical reduction are commonly required.

Overall, silver sintering currently provides the most balanced combination of thermal, electrical, mechanical, and high-temperature performance. Copper sintering offers superior economic potential and scalability if oxidation can be effectively controlled, whereas TLPS is more suitable for applications prioritizing low bonding temperature, moderate cost, and compatibility with established packaging processes.

3. Analysis and challenges

3.1. Transient liquid-phase sintering/bonding materials

Zhang et al. developed a bonding technology based on a Cu@Sn core-shell transient liquid-phase sintering route for high-temperature power electronics interconnection [7]. As illustrated in Figure 1, Cu particles were first coated with a Sn shell by a methylate electroplating method and then pressed into a preformed sheet, which was used as the bonding interlayer. The Cu@Sn preform was reflowed at 250–280 °C for 40 min under an extremely low pressure of 0.1×10^{-3} MPa. According to the morphology and elemental analysis in Figure 2, the prepared particles exhibited a clear core-shell structure, with a uniform Sn layer of approximately 1–3 μm surrounding the Cu core. The authors further used cross-sectional microscopy, EDS line scanning, XRD, nano-indentation, shear testing, electrical resistivity measurement, laser flash thermal analysis, and DSC to characterize the interfacial reaction, phase evolution, mechanical response, and transport properties of the TLPS joint.



Figure 1: Schematic of the fabrication process of the preform and joint [7].

Figure 1. Schematic of the fabrication process of the preform and joint [7]



Figure 2: (a) Surface morphology, (b) and (c) profile morphology, (d) profile EDS results of Cu@Sn core–shell structure powder [7].

Figure 2. (a) Surface morphology, (b) and (c) profile morphology, (d) profile EDS results of Cu@Sn core–shell structure powder [7]

The performance results show good high-temperature stability of the Cu@Sn TLPS joint and relatively good electrical, thermal, and mechanical properties. In reflow, the low-melting Sn shell reacted with Cu and changed mainly into Cu_3Sn; this phase wrapped the residual Cu particles and gave a bondline of high remelting point. The joint could bear up to 600 °C; this is the main advantage of TLPS, low processing temperature with high service temperature. The shear strength was 48.9 MPa after reflowing at 280 °C for 40 min. After aging at 400 °C for 1000 h, a shear strength of 44.6 MPa was still kept, so the thermal stability is good. The Young's modulus and the hardness reached 98.35 GPa and 2.62 GPa, below those of a pure Cu_3Sn joint, and the capability of

DOI: 10.54254/2755-2721/2026.37704

stress relaxation was therefore better. A thermal conductivity of 148 $W \cdot m^{-1} \cdot K^{-1}$ and an electrical resistivity of 5.1 μΩ·cm were also reached, better than in many Cu/Sn TLPS systems [7].

However, several limitations still existed in the Cu@Sn TLPS strategy. First, core-shell powder preparation and preform pressing were needed, and both are more complex than direct paste printing; manufacturing flexibility for fine-patterned or large-area power modules may thus be limited. Second, Cu_3Sn gave a high remelting temperature and good thermal stability, but too much intermetallic compound made the joint brittle and lowered its tolerance to thermomechanical mismatch. A recent TLPS study found that the Cu/SnAgCu powder fraction and the sintering time had a strong effect on how Cu_6Sn_5, Cu_3Sn, and Ag_3Sn formed, on shear strength, and on joint densification [8]. Therefore, the reliability of TLPS joints depended not only on achieving complete reaction, but also on controlling phase balance, void evolution, and residual ductile phases. Although Cu@Sn TLPS was attractive for high-temperature packaging, future work should focus on printable formulations, void suppression, phase regulation, and long-term thermal-cycling reliability.

3.2. Silver sintering

Ag sintering pastes utilize metallic Ag nanoparticles to form interconnections. Shen et al. developed an organic-amine-assisted surface modification strategy to improve the sintering behavior of commercial Ag nanoparticle paste [9]. As shown in Figure 3, commercial Ag nanoparticles were first cleaned with ethanol by ultrasonic dispersion and freezing centrifugation, and then modified with four primary amines with different alkyl chain lengths, namely n-octylamine (NOA), dodecylamine (DDA), hexadecylamine (HDA), and octadecylamine (ODA). After removing excess amines, the particles were dispersed in a tert-butanol/ethanol mixture, frozen, and freeze-dried to obtain surface-modified Ag nanopowders. These powders were mixed with organic solvents to form Ag pastes with 85 wt.% Ag content. The pastes were dispensed onto Ni/Au-coated DBC substrates, assembled into sandwich joints, and pressurelessly sintered at 250 °C for different holding times. FTIR, EDS, and XPS were applied to verify amine coating, while resistivity, SEM, shear testing, cross-sectional porosity, and thermal analysis were used to evaluate sintering quality and joint performance.



Figure 3: Nano-Ag paste preparation and pressureless sintering bonding process [9].

Figure 3. Nano-Ag paste preparation and pressureless sintering bonding process [9]

The performance results indicated that NOA modification gave the most balanced electrical and mechanical advantages rather than merely improving one metric. After sintering at 250 °C for 30 min, the Ag-NOA film achieved a resistivity of 7.31 μΩ·cm, 62.8% lower than that of Ag-0 (no amine treatment) (19.63 μΩ·cm), while Ag-DDA gave 12.02 μΩ·cm. By contrast, Ag-HDA and Ag-ODA increased the resistivity to 58.66 and 80.16 μΩ·cm, showing that long-chain amines hindered the formation of a conductive Ag network. Mechanically, Ag-NOA joints reached 61.8 MPa, compared with 35.7 MPa for Ag-0, representing a 73.1% improvement; Ag-DDA was intermediate, while Ag-HDA and Ag-ODA remained around 35 MPa. The advantage of NOA therefore lay in balancing storage dispersion and rapid ligand removal, enabling Ag diffusion, neck growth, and densification. When the holding time was increased to 60 min, the resistivity decreased to 5.3 μΩ·cm, the shear strength increased to 69.3 MPa, and the porosity fell to 3.43%, confirming stronger interparticle and Ag-Au interfacial connectivity.

DOI: 10.54254/2755-2721/2026.37704

However, the strategy for Ag sintering still faced scale-up and reliability challenges. The joints in Shen et al.'s report were small DBC sandwich samples, so the uniform removal of organics, paste shrinkage, and void evolution in large-area SiC modules were not fully verified. This limitation was important because large-area Ag-sintering research on >2400 mm² SiC module substrate bonding showed that bonding quality was strongly affected by drying conditions, pressure-assisted processing, and sintering uniformity [10]. In addition, the results indicated that surface coating was a double-edged strategy: NOA improved dispersion and densification, whereas longer-chain amines caused more residues, poorer diffusion, larger porosity, and lower strength [9]. Since sintered Ag is intrinsically porous, its reliability was also governed by creep, fatigue, thermal cycling, and microstructural coarsening rather than initial shear strength alone [11, 12]. Therefore, organic-amine-modified nano-Ag paste remained promising, but future work should address residue control, large-area void suppression, and long-term power-module reliability.

3.3. Copper sintering

Cu sintering is a technology to replace Ag sintering due to cost concerns. Liu et al. designed a pressure-assisted Cu sintering strategy for SiC power-electronics die attachment by using treated Cu quasi-nanoparticles (Cu QNPs) as the bonding interlayer [13]. As shown in Figure 4, the Cu particles exhibited quasi-spherical morphology and relatively uniform dispersion, while the TEM image revealed a thin surface coating layer formed after chemical treatment. This coating was introduced to improve the oxidation resistance and processability of Cu particles before sintering. In the experimental procedure shown in Figure 5, the treated Cu QNPs were mixed with ethylene glycol and terpineol to prepare a printable Cu paste, which was then patterned onto bare DBC substrates. After drying at 120 °C for 5 min, Ag-coated dummy chips were placed on the Cu paste, followed by pressure-assisted sintering in nitrogen. The authors systematically varied the sintering pressure, temperature, and time, and evaluated the joints by die-shear testing, SEM fracture analysis, cross-sectional porosity analysis, and EDS.

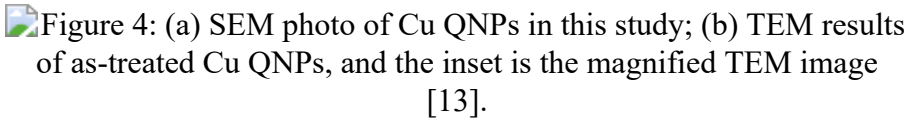
Figure 4: (a) SEM photo of Cu QNPs in this study; (b) TEM results of as-treated Cu QNPs, and the inset is the magnified TEM image [13].

Figure 4. (a) SEM photo of Cu QNPs in this study; (b) TEM results of as-treated Cu QNPs, and the inset is the magnified TEM image [13]

The results showed that Cu sintering provided high bonding strength under a relatively short processing time, especially when pressure and temperature were properly optimized. At 250 °C for 3 min, the joint reached 36.5 MPa under 5 MPa pressure, while increasing the pressure to 30 MPa raised the shear strength to 116 MPa. Temperature also played a decisive role: sintering at 210–230 °C already produced strengths above 30 MPa, whereas increasing the temperature to 270 °C enhanced the strength to over 120 MPa. The above data show that strong joints can be formed by Cu quasi-nanoparticles in a short time once enough pressure and thermal activation are given. Closer particle contact, faster neck growth, a continuous sintered network, isolated pores, and a change of the fracture mode from brittle to more ductile are the reasons for the higher bonding strength. With processing time, practical feasibility, and bonding strength all taken into account, a suitable sintering condition is 250 °C for 3 min under 20 MPa.

DOI: 10.54254/2755-2721/2026.37704



Figure 5: Schematic diagrams of Cu paste preparation, pressure-assisted sintering, and joint evaluation [13].

Figure 5. Schematic diagrams of Cu paste preparation, pressure-assisted sintering, and joint evaluation [13]

On the other hand, Cu sintering in practical module-level application still met several challenges. First, external pressure strongly affected the high shear strength; 5 MPa already gave acceptable bonding, but 30 MPa was needed for the best strength, so stress can concentrate in fragile power chips and the equipment becomes more complex. Second, poor bonding performance was found to come from incomplete organic burnout and insufficient sintering of the Cu quasi-nanoparticles, so residue control was still a main problem [13]. Third, oxidation affected Cu sintering more than Ag sintering; paste formulation, atmosphere, reducing components, and surface condition therefore all had to be controlled carefully. The same limitation also appeared in later studies of large-area Cu-Cu bonding, in which interfacial bonding quality, fracture behavior, and densification still depended largely on temperature and pressure [14]. Therefore, Cu sintering had clear cost and electromigration advantages, but its broader use still required better oxidation suppression, lower-pressure processing, and large-area reliability validation.

4. Discussion and suggestions

Table 1 summarizes the main advantages and disadvantages of the three interconnection methods for next-generation power devices. TLPS is attractive because it can achieve bonding at relatively low temperature while forming high-remelting intermetallic compounds for high-temperature service. Therefore, it provides relatively high shear strength, moderate material cost, and good compatibility with Cu-based metallization systems. However, the same intermetallic compounds that provide thermal stability can also introduce brittleness. Residual porosity, volume shrinkage, incomplete reaction, and complex phase evolution may further reduce joint toughness and thermal-cycling reliability. Therefore, TLPS is more suitable for applications where high remelting temperature, moderate cost, and process compatibility are prioritized. Future work should not simply pursue complete intermetallic formation; instead, it should focus on balancing intermetallic phases and residual ductile phases, suppressing voids, improving printable formulations, and enhancing long-term reliability under thermal cycling. In particular, controlling the growth of Cu-Sn intermetallic compounds is essential, because excessive brittle phases may weaken the joint even when the initial shear strength is high.

Table 1. Comparison of various interconnection methods for power devices

Type	Advantages	Disadvantages / Challenges
TLPS	- High shear strength - Low-temperature bonding and high-temperature service capability - Moderate material cost - Good compatibility with Cu-based metallization	- Brittleness of intermetallic compounds - Residual porosity and volume shrinkage - Complex phase evolution - Limited toughness under thermal cycling

DOI: 10.54254/2755-2721/2026.37704

Ag sintering	- Excellent thermal and electrical conductivity - High bonding strength - Good high-temperature stability - Mature technology for SiC power modules	- High material cost - Possible electrochemical migration - Pressure often required for large-area bonding - Porosity and organic-residue issues
Cu sintering	- Lower cost than Ag sintering - Good thermal and electrical conductivity - Better resistance to electrochemical migration - Good compatibility with Cu substrates	- Strong oxidation sensitivity - Need for reducing atmosphere or protective coating - Pressure-dependent densification - Large-area bonding uniformity challenge

In thermal, electrical, and mechanical performance, Ag sintering is relatively well balanced. It has strong bonding strength, low electrical resistivity, high thermal conductivity, and good stability at high temperature; SiC and GaN power devices need reliable electrical interconnection and efficient heat dissipation, and it therefore fits them well. Different from TLPS, Ag sintering does not depend on brittle intermetallic compounds; thermomechanical deformation can also be taken up by its porous metallic network once the pore structure is well controlled. However, some practical limitations still exist in this technology. Electrochemical migration may occur in a humid environment under electrical bias, and the high price of Ag raises the packaging cost. Pressureless sintering has been realized on small-area joints, but pressure is often still helpful in large-area module bonding, because it reduces void formation and improves interfacial contact. Ag sintering is thus more suitable for modules of high reliability and high performance where cost is not the first limitation. Further work should cover void control over large areas, organic-residue removal, low-cost Ag-based composite pastes, and reliability in humid environments and under thermal and power cycling. The effect of the pore structure on long-term degradation also needs attention, because a high strength at the beginning does not always mean stable service performance.

In terms of cost and industrial scalability, Cu sintering has the greatest potential. The price of Cu is much lower than that of Ag, and its electrical and thermal conductivity is still good. It also shows better resistance to electrochemical migration and good compatibility with Cu substrates, DBC metallization, and Cu clips. Because of the above features, Cu sintering is of interest for cost-sensitive uses such as automotive power modules. Its main problem, however, is oxidation. Cu oxides inhibit interparticle diffusion, neck growth, and densification, leading to unstable bonding strength. In many studies, high-strength Cu joints were achieved only under sufficient pressure, controlled atmosphere, surface coating, or chemical reduction. This means that Cu sintering is not only a material issue but also a process-integration challenge. Therefore, future studies should focus on oxidation-resistant Cu particles, self-reducing paste systems, lower-pressure sintering, and large-area bonding uniformity. If oxidation and pressure dependence can be effectively controlled, Cu sintering may become the most economically competitive interconnection technology for next-generation power devices. At the same time, its process window should be carefully optimized to avoid excessive pressure-induced damage to fragile chips.

Overall, silver sintering currently provides the most balanced combination of thermal, electrical, mechanical, and high-temperature performance. Copper sintering offers superior economic potential and scalability if oxidation can be effectively controlled, whereas TLPS is more suitable for applications prioritizing low bonding temperature, moderate cost, and compatibility with established packaging processes.

DOI: 10.54254/2755-2721/2026.37704

5. Conclusion

This review focused on advanced interconnection materials for next-generation power devices, especially in the context of new energy vehicles and wide-bandgap semiconductor packaging. SiC and GaN devices now work under more severe thermomechanical conditions, at higher power density and higher temperature; conventional solder-based interconnections can therefore no longer satisfy the requirements of electrical stability, heat dissipation, and long-term reliability. For this reason, three typical interconnection technologies were discussed and compared, that is, transient liquid-phase sintering/bonding, silver sintering, and copper sintering.

TLPS is a useful method for low-temperature bonding with high-temperature service. In TLPS the low-melting components turn into intermetallic compounds of high remelting point, so the joints obtain good thermal stability and fairly high bonding strength. On the other hand, volume shrinkage, residual pores, complex phase evolution, and brittle intermetallic compounds may lower joint toughness and thermal-cycling reliability. Thus, TLPS fits applications where moderate cost and a high remelting temperature come first, but its void evolution and phase composition need careful control.

Ag sintering keeps a balance among mechanical, electrical, and thermal properties in power packaging. Sintered Ag joints have strong shear strength, low electrical resistivity, high thermal conductivity, and good stability when the temperature is high; such joints are therefore of interest for SiC power modules. However, porosity, residual organics, electrochemical migration, the high cost of Ag, and the difficulty of uniform bonding over large areas still limit its wider use. Further improvement points to reliable pressureless sintering of large-area joints and to lower-cost Ag-based composites.

Cu sintering is a good choice when cost and manufacturing scale are the main concerns. Copper has good thermal and electrical conductivity, and compared with Ag its cost is lower and its resistance to electrochemical migration better. Oxidation is its main limitation, since surface oxides can hold back interparticle diffusion, neck formation, and densification during sintering. For practical use, self-reducing pastes, oxidation-resistant particles, and processes giving dense joints at lower pressure are needed.

In the end, interconnection materials should not be chosen by initial shear strength alone. Cost, scalability, bonding pressure, processing temperature, oxidation resistance, electrical resistivity, thermal conductivity, and long-term reliability also count. Hybrid approaches may combine the performance of Ag, the lower cost of Cu, and the high-temperature capability of TLPS.

References

[1] Wang, L., Yang, F., Pei, Y., Yang, X., & Lorenz, L. (2026). Packaging and integration of silicon carbide power devices. *Nature Reviews Electrical Engineering, 3*(3), 157–172. https://doi.org/10.1038/s44287-026-00263-0

[2] Hou, F., Sun, Z., Su, M., Fan, J., You, X., Li, J., Wang, Q., Cao, L., & Zhang, G. (2024). Review of die-attach materials for SiC high-temperature packaging. *IEEE Transactions on Power Electronics, 39*(10), 13471–13486. https://doi.org/10.1109/TPEL.2024.3417529

[3] Yang, F., Wang, L., Kong, H., Zhu, M., Liu, X., Lu, X., Qin, M., Zhang, T., Gan, Y., & Jia, L. (2023). Compact-interleaved packaging method of power module with dynamic characterization of 4H-SiC MOSFET and development of power electronic converter at extremely high junction temperature. *IEEE Transactions on Power Electronics, 38*(1), 417–434. https://doi.org/10.1109/TPEL.2022.3198835

[4] Wu, N., & Li, Y. (2025). A review of novel die attach materials for high-temperature WBG power electronic applications. *Materials, 18*(16), 3841. https://doi.org/10.3390/ma18163841

[5] Wu, W., Yang, F., Hu, B., & Li, M. (2021). Pressureless sintering behavior of nano-silver paste for large area chip interconnection. *Transactions of the China Welding Institution, 42*(1), 83–90.

DOI: 10.54254/2755-2721/2026.37704

https://doi.org/10.12073/j.hjxb.20201016002
[6] Zuo, Y., Carter-Searjeant, S., Green, M., Mills, L., & Mannan, S. H. (2020). High bond strength Cu joints fabricated by rapid and pressureless in situ reduction-sintering of Cu nanoparticles. *Materials Letters, 276*, 128260. https://doi.org/10.1016/j.matlet.2020.128260
[7] Zhang, H., Xu, H., Liu, X., & Xu, J. (2022). Fabrication of Cu@Sn TLPS joint for high temperature power electronics application. *RSC Advances, 12*(45), 29063–29069. https://doi.org/10.1039/D2RA04606G
[8] Tran, D.-P., Liu, Y.-T., & Chen, C. (2024). Effects of Cu/SnAgCu powder fraction and sintering time on microstructure and mechanical properties of transient liquid phase sintered joints. *Materials, 17*(9), 2004. https://doi.org/10.3390/ma17092004
[9] Shen, X., Li, J., & Xi, S. (2022). High strength die-attach joint formation by pressureless sintering of organic amine modified Ag nanoparticle paste. *Nanomaterials, 12*(19), 3351. https://doi.org/10.3390/nano12193351
[10] Xue, J., & Li, X. (2024). High-pressure-assisted large-area (>2400 mm2) sintered-silver substrate bonding for SiC power module packaging. *Materials, 17*(8), 1911. https://doi.org/10.3390/ma17081911
[11] Sghuri, A., Billaud, Y., Signor, L., Saury, D., & Milhet, X. (2023). Experimental investigation of thermal conductivity during aging of nanoporous sintered silver. *Acta Materialia, 257*, 119109. https://doi.org/10.1016/j.actamat.2023.119109
[12] Wakamoto, K., & Namazu, T. (2024). Mechanical characterization of sintered silver materials for power device packaging: A review. *Energies, 17*(16), 4105. https://doi.org/10.3390/en17164105
[13] Liu, X., Li, S., Fan, J., Jiang, J., Liu, Y., Ye, H., & Zhang, G. (2022). Microstructural evolution, fracture behavior and bonding mechanisms study of copper sintering on bare DBC substrate for SiC power electronics packaging. *Journal of Materials Research and Technology, 19*, 1407–1421. https://doi.org/10.1016/j.jmrt.2022.05.122
[14] Li, W. Y., Chen, C. T., Ueshima, M., Kobatake, T., & Suganuma, K. (2023). Large area bare Cu-Cu interconnection using micro-Cu paste at different sintering temperatures and pressures. *Microelectronics Reliability, 150*, 115105. https://doi.org/10.1016/j.microrel.2023.115105