Proceedings of the 4th International Conference on Functional Materials and Civil Engineering
DOI: 10.54254/2755-2721/2026.36974

Research on the Application of Cu/W Composites in Thermal Management of Electronic Packaging

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Abstract. The copper-tungsten (Cu/W) composite material relies on the Cu phase to undertake the major heat-transfer function and uses the W phase to restrict thermal expansion. Therefore, its composition can be designed to balance the thermal conductivity and dimensional stability required for packaging heat sinks. Starting from the problems of heat-flow transmission and thermal mismatch in electronic packaging, this paper reviews the research progress in preparation and application of Cu/W materials. By comparing the densification routes including powder metallurgy, infiltration, hot-press sintering and spark plasma sintering, this work analyzes the influences of pores, connectivity of Cu phase and W-Cu interfaces on thermal conductivity and thermal expansion behaviour. The functions and limitations of activated sintering, surface coating and functionally graded structures are also discussed. Existing studies indicate that performance optimization should not take relative density as the sole objective. Interfacial thermal resistance, processing cost and thermal-cycling stability also need to be considered simultaneously. On this basis, this paper summarizes the unsolved problems in large-scale preparation and packaging reliability, and provides references for material selection and structural design of Cu/W heat sinks and packaging substrates.

Keywords: copper-tungsten composite, electronic packaging, thermal management, interface regulation, thermophysical properties

1. Introduction

1.1. Research background

1.1.1. Development demands of electronic packaging technology and the value of thermal-management technology

With the increase in power density of electronic devices, the temperature gradient inside the package and thermal mismatch between materials will rise simultaneously. The packaging layer not only realizes interconnection and physical protection, but also transfers heat generated by chips to external heat-dissipation structures. Therefore, packaging materials should be evaluated by thermal expansion coefficient, interfacial strength and property retention after repeated temperature cycles, rather than merely compared by room-temperature thermal conductivity.

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Heat produced by chips generally passes sequentially through the thermal interface layer, packaging substrate or heat sink, and is finally released into the environment via cooling fins [1]. Excessively high thermal resistance in any layer will raise the junction temperature, and interfacial voids and delamination often aggravate this problem. Figure 1 shows the typical heat-transfer path adopted in this paper.

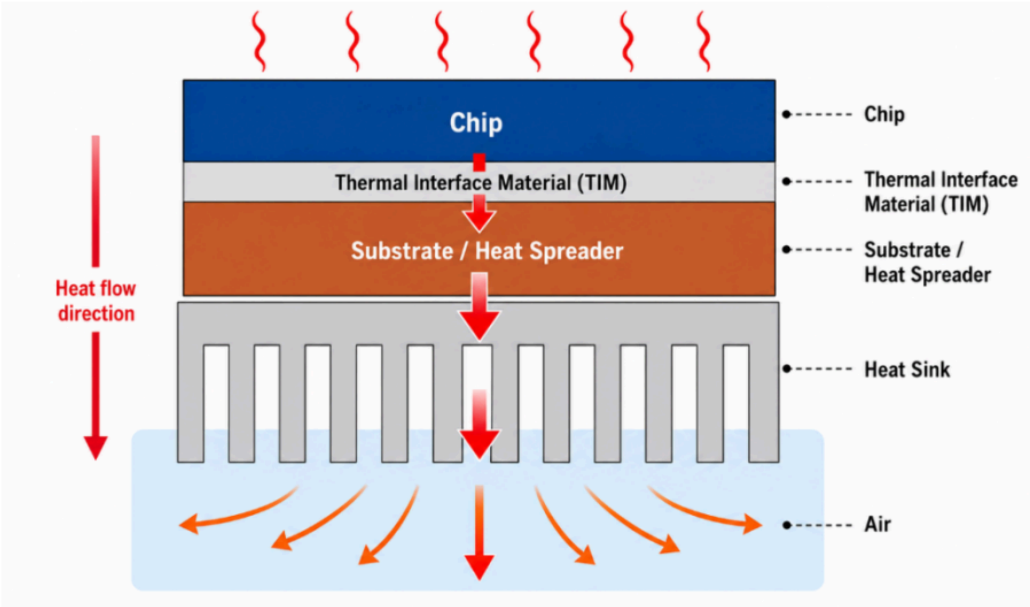

Figure 1. Typical heat transfer path in electronic packaging

2.5D/3D integration, system-in-package and Chiplet technology increase the quantity of interconnections and heat sources per unit area. As a result, local heat-flux density and package warpage control become more critical [2, 3]. Figure 2 illustrates the typical structures of 2.5D/3D packaging and wafer-level packaging.

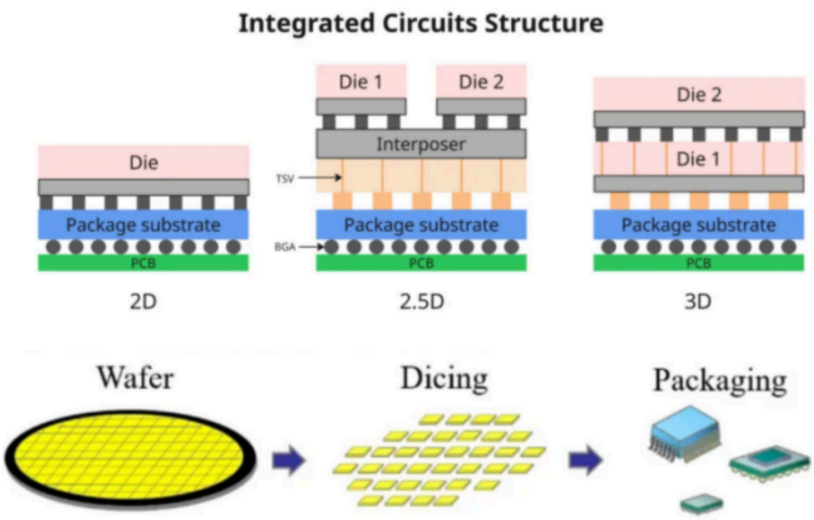

Figure 2. Schematic diagram of 2.5D/3D packaging and wafer-level packaging

DOI: 10.54254/2755-2721/2026.36974

1.1.2. Classification of electronic packaging substrate materials and research advantages of Cu/W composites

Common thermal-management materials for electronic packaging include Cu, Al, Mo-Cu, Cu/W, AlSiC, Cu-Mo-Cu laminated composites and diamond-copper composites. Cu and Al possess high thermal conductivity, while their high thermal expansion coefficients easily cause thermal mismatch with Si, GaAs or GaN chips. AlSiC features low density and adjustable CTE, yet its thermal conductivity is usually limited. Diamond-copper composites exhibit great potential for high thermal conductivity, but interfacial bonding, manufacturing cost and large-scale preparation still remain engineering obstacles [4].

The design goal of Cu/W composites is not to pursue the maximum thermal conductivity. Instead, the two phases perform different functions: the W phase reduces thermal expansion and provides structural rigidity, and the Cu phase forms heat-conducting and electric-conducting channels. Changing the W/Cu mass ratio can adjust the above-mentioned properties synchronously, so this material can be selected to match chips, ceramic substrates and packaging bases [5, 6].

1.2. Basic properties and research status of Cu/W materials

1.2.1. Physical characteristics of cu/w materials and their adaptability to electronic packaging

Cu/W is generally defined as a pseudo-alloy, because tungsten and copper are nearly immiscible under conventional conditions and their interfacial wettability is relatively poor [5]. Its macroscopic properties are derived from the micro-scale combination of the two phases rather than solid-solution effects: the W phase provides dimensional constraint, and the Cu phase undertakes heat and electric conduction.

Composition variation leads to obvious property trade-offs. Higher tungsten content usually lowers the thermal expansion coefficient and improves compatibility with chips or ceramic substrates. Nevertheless, the decline of Cu-phase connectivity will weaken heat-conducting paths. Hence, composition design should take allowable thermal resistance, operating temperature range and connection mode of specific packages into consideration, instead of relying on a single performance indicator [6]. Figure 3 presents the typical two-phase microstructure of Cu/W composites.

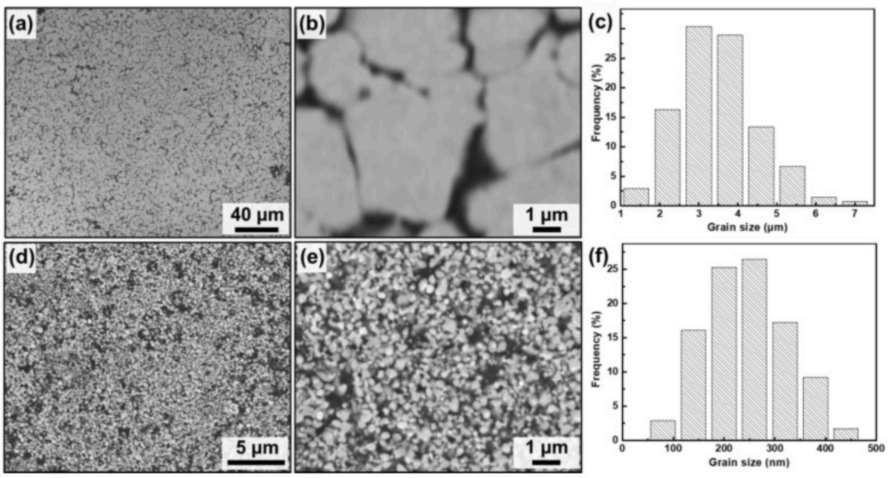

Figure 3. Schematic diagram of the two-phase structure of Cu/W composite

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1.2.2. Research progress and achievements of Cu/W materials in electronic packaging

Current studies are generally carried out along three technical routes: reducing initial pores by adjusting powder particle size and forming methods; improving Cu-phase continuity with porous tungsten skeletons and infiltration processes; regulating interfaces and thermal stress by adding activated elements or constructing gradient structures [7, 8]. All these methods aim to reduce pores and interfacial thermal resistance, while compromises exist in manufacturing cost, component dimension and heat-conduction loss.

At the device level, Cu/W materials have been applied in microwave power devices, laser diodes, hermetic packages and heat-dissipation structures for power semiconductors. Their main function is to rapidly spread heat away from chips and limit thermal deformation difference between packaging bases and chips.

1.3. Core problems of Cu/W materials applied in electronic packaging

When Cu/W composites are used for electronic packaging, densification, interfacial bonding and composition design should be considered comprehensively. Since tungsten and copper are almost immiscible under conventional conditions and there is a huge gap between their melting points, internal pores are difficult to eliminate completely by ordinary sintering processes. If molten copper poorly wets tungsten, extra thermal resistance will be generated at the W-Cu interface. After repeated heating and cooling cycles, pores or weakly bonded interfaces tend to become crack initiation sites, and delamination may occur in severe cases. On the other hand, the W/Cu ratio brings an inherent property conflict. Increasing copper content helps form continuous heat-conducting channels, yet raises the overall thermal expansion coefficient of the material. Higher tungsten content improves dimensional stability, but may damage the continuity of copper phase [9]. Accordingly, it is inadvisable to adjust densification condition, interfacial state or component ratio separately.

In practical design, the proper W/Cu ratio can be determined according to the thermal expansion properties of chips, ceramic substrates and other adjacent materials. Afterwards, measures such as optimizing pore structure of tungsten skeletons, improving interfacial wettability and surface modification can be adopted to guarantee the continuous distribution of Cu phase inside the material. Optimization results should not be judged merely by post-sintering relative density or room-temperature thermal conductivity. It is also necessary to compare thermal resistance variation before and after thermal cycles and inspect whether failure phenomena including cracks and delamination appear at interfaces.

1.4. Research content, framework and significance of this paper

This paper is organized around the relationship between preparation processes, microstructures, material properties and packaging applications. Section 2 mainly analyzes the influences of infiltration, hot-press sintering, spark plasma sintering and other processes on pore distribution, particle morphology and interfacial conditions. Section 3 discusses modification approaches including activated elements, surface coatings and gradient structures, and explores their effects and limitations in improving densification, interfacial bonding and thermal-stress distribution. Combined with thermal conductivity, thermal-expansion behaviour, mechanical performance and thermal-cycle reliability, Section 4 evaluates the applicable conditions of Cu/W materials in different electronic-packaging scenarios.

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2. Preparation technology and structure regulation of Cu/W materials

2.1. Densification principle and packaging-related performance requirements of Cu/W materials

For Cu/W substrates used in electronic packaging, relative density is undoubtedly important. Nevertheless, it is the formation of continuous and stable heat-transfer channels inside the material that actually determines the heat-dissipation performance. Residual pores break the connectivity of the Cu phase and force heat flow to detour locally. Stress concentration also tends to occur around pores under external force or repeated temperature variation. Therefore, relative density can reflect the basic densification level of materials, yet it cannot independently characterize the thermal property and service reliability of substrates. Even if the porosity is reduced, the actual thermal conductivity will still be impaired when the W-Cu interfacial bonding is weak or the interfacial thermal resistance is high.

The difficulty in densifying Cu/W materials mainly originates from the limited mutual solubility and wettability between the two phases. In conventional diffusion sintering, mass transfer between tungsten and copper particles proceeds slowly, and the shrinkage generated during sintering is usually insufficient to completely eliminate internal pores. In practical production, powder particle size, sintering pressure and liquid-phase filling process are generally adjusted according to material composition and component requirements. A small amount of activated elements can also be added to promote particle contact, pore closure and interfacial bonding [8, 9]. These measures produce different effects. Process design should balance densification effect, interfacial condition and possible thermal-conductivity loss.

2.2. Fabrication of Cu/W materials via powder metallurgy and process regulation

2.2.1. Mechanical alloying: powder mixing and homogeneity optimization

In the pre-treatment of Cu-W powder, mechanical alloying is mainly adopted to improve the mixing state of two kinds of powders. During ball-milling, original powder agglomerates are gradually broken, and the contact distance between W particles and Cu particles decreases accordingly, which provides a relatively homogeneous microstructure foundation for subsequent sintering [10]. However, the ball-milling performance will not keep improving with the increase of treatment intensity. Excessively long milling time or improper ball-to-powder ratio may introduce impurities caused by the wear of milling balls and milling jars. Poor control of protective atmosphere can easily lead to oxidation on powder surfaces. All these problems affect the heat-transfer behaviour at the W-Cu interface, and may offset the benefits brought by powder homogenization in serious cases.

2.2.2. Cold-press sintering: densification behaviour and pore control

The process combining cold pressing and subsequent sintering is relatively simple and easy to implement for Cu/W bulk components with regular shapes. Its main limitation lies in the densification degree. Due to the low diffusion rate between Cu and W phases, inter-particle bonding and overall material shrinkage during sintering are rather limited, and closed pores formed inside green compacts are usually hard to remove. Appropriately increasing compaction pressure, adopting powder gradation with different particle sizes or prolonging sintering holding time can reduce pores and optimize their distribution to a certain extent. Nevertheless, these adjustments show limited capacity to eliminate closed pores. Consequently, the relative density of as-prepared materials is generally lower than that obtained by pressure-assisted processes (hot pressing, SPS) or infiltration methods [10].

2.2.3. Hot-press sintering: influences of temperature and pressure parameters

Hot-press sintering integrates temperature rise and external pressure. The applied pressure promotes particle sliding and pore collapse, so the resulting materials usually possess higher density and strength compared with pressure-free sintering [11]. This technology requires high investment in moulds and equipment, and its application is restricted for components with complex shapes or large dimensions.

2.3. Fabrication of Cu/W materials by infiltration method and improvement of interfacial wettability

2.3.1. Preform fabrication: tungsten skeleton design and porosity regulation

The infiltration method first prepares a tungsten pre-form with interconnected pores, and then fills the pores with molten copper by capillary force. The final microstructure depends on whether the porosity of the pre-form matches the target copper content, as well as the continuity of pore size and channels. Isolated pores or abrupt changes in pore diameter may lead to uninfiltrated zones.

2.3.2. Infiltration process: molten copper penetration and interfacial-bonding mechanism

During infiltration, whether molten copper can flow into the tungsten pre-form smoothly is mainly determined by its wettability on the tungsten skeleton and the flow conditions inside pore channels. Insufficient wettability prevents molten copper from fully filling the interconnected pores inside the skeleton, which may leave uninfiltrated regions in the final material. Increasing infiltration temperature, moderately extending holding time or adding a small quantity of active elements generally helps improve the infiltration performance of liquid copper. However, higher temperature and longer holding time are not always beneficial. Excessive thermal effect may cause grain coarsening and aggravate interfacial reactions between W and Cu. Studies on W-15Cu materials indicate [12] that favourable thermal conductivity can be achieved under reasonable infiltration parameters combined with post-annealing treatment. The basic infiltration procedure for Cu/W composites is shown in Figure 4.

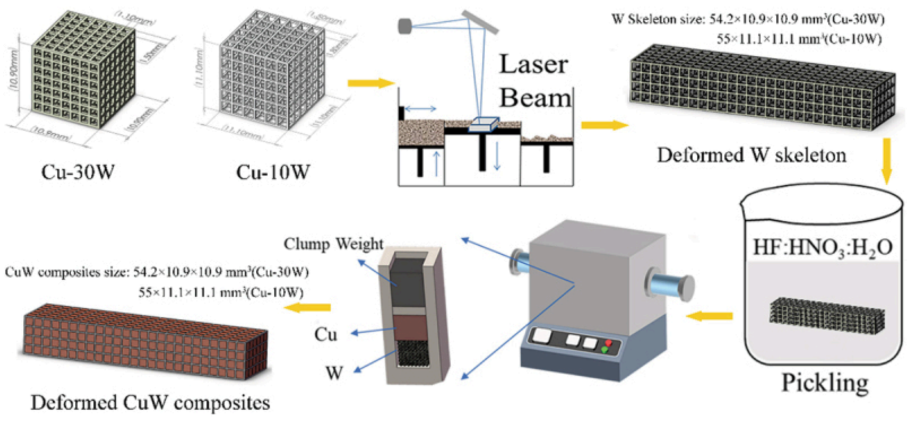

Figure 4. Preparation process of Cu/W composite by infiltration method

DOI: 10.54254/2755-2721/2026.36974

2.4. Fabrication of Cu/W materials via spark plasma sintering (SPS) and rapid densification

2.4.1. Effects of heating rate and holding pressure time on relative density

Spark plasma sintering achieves rapid temperature rise by pulsed electric current, and completes sintering under axial pressure. The short thermal cycle facilitates pore closure before obvious particle coarsening. For Cu/W composites, the increased particle contact area and plastic flow of copper phase jointly drive densification.

2.4.2. Interfacial reaction and microstructure evolution

Rapid sintering restrains the grain growth of tungsten and the coarsening of copper phase. The obtained microstructure is usually fine and homogeneously distributed, which is beneficial to mechanical strength and dimensional stability [13]. Nevertheless, the maximum component size for SPS is limited by mould geometry and current distribution, and the equipment cost is high. Temperature uniformity remains a key problem to be solved for scaled-up manufacturing.

2.5. Regulation rules of preparation processes on microstructure, relative density and thermophysical properties of Cu/W materials

Differences among various fabrication processes can be summarized as distinct pore-elimination mechanisms. Infiltration fills interconnected pores with molten copper and is suitable for high-tungsten-content materials. Conventional powder metallurgy has low cost yet is sensitive to powder mixing quality and sintering window. Hot pressing and SPS shorten the densification path through external pressure, among which SPS provides a shorter thermal cycle. Ultimately, these processes affect thermal conductivity, coefficient of thermal expansion and service reliability via porosity, Cu-phase connectivity, tungsten particle size and interfacial state. Table 1 compares the main fabrication processes based on the above-mentioned factors.

Table 1. Main preparation methods and characteristics of Cu/W alloy

Preparation Method	Infiltration	High-Temperature Liquid-Phase Sintering	Activated Liquid-Phase Sintering	Hot-Press Sintering	Spark Plasma Sintering
Process Principle	Liquid Cu infiltrates the W skeleton	W/Cu powders are mixed and sintered at high temperature	Ni, Co, Fe, and other activating agents are added	High-temperature pressing promotes densification	Rapid sintering using pulsed current and pressure
Advantages	High density; suitable for high W content	Mature process; relatively low cost	Lower sintering temperature and increased density	High density; good mechanical properties	Rapid sintering; fine microstructure
Disadvantages	Dependent on the pore structure of the skeleton	Limited densification and uniformity	Activating agents may reduce thermal conductivity	High equipment cost; size limitations	Expensive equipment; difficult scale-up
References	[5, 7, 12]	[5, 6]	[5, 8]	[6, 9, 11]	[6, 11, 13]

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3. Performance-modification strategies and mechanisms of Cu/W materials

3.1. Interface-modification strategies and improvement mechanism of thermophysical properties

3.1.1. Addition of sintering aids: improving W-Cu wettability and densification efficiency

To solve the poor wettability between tungsten and copper, a small amount of Ni, Co or Fe is often added for activation treatment during preparation. These elements can promote particle rearrangement in the sintering process and accelerate diffusion at the W-Cu interface, which helps reduce residual pores and strengthen the bonding between two phases. Nevertheless, the dosage of activated elements should be strictly controlled. Excessive activated elements entering the copper phase or forming new second-phase particles inside the material will increase phonon scattering during heat transfer and reduce the thermal conductivity. Therefore, practical processes should not merely pursue high relative density. A trade-off between interface improvement and thermal-conducting performance is required.

3.1.2. Surface plating: enhancing interfacial bonding strength and thermal-fatigue resistance

In electronic packaging, Cu/W substrates usually need to be bonded with solders, ceramic layers or metal shells. The surface condition of substrates affects welding quality and air-tight performance. Coatings of Ni, Au or Ni/Au can improve surface wettability and prevent oxidation. However, excessively thick coatings or thick reaction layers generated at bonding interfaces during service will raise thermal resistance. Accordingly, the coating thickness in the layered structure shown in Figure 5 should be determined by both bonding reliability and heat-dissipation requirements.

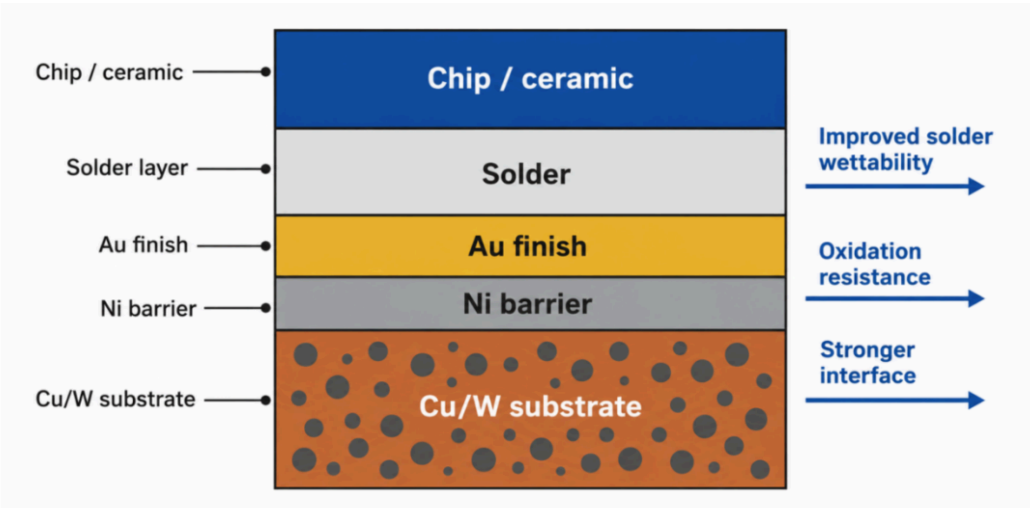

Figure 5. Schematic diagram of surface coating and soldering interface structure of Cu/W substrate

3.2. Gradient-structure design and regulation of coefficient of thermal expansion

3.2.1. Composition gradient: realizing continuous transition of CTE

Gradient structures disperse the abrupt thermal-expansion difference between Cu/W materials and chips or ceramic substrates into multiple layers. Gradually increasing or reducing tungsten content

DOI: 10.54254/2755-2721/2026.36974

along the thickness direction achieves continuous transition of thermal expansion coefficient and lowers peak stress during thermal cycles. For instance, higher tungsten content is adopted on the chip-side surface, while more copper is added on the radiator-side surface to enhance heat spreading. Figure 6 illustrates this compositional-design idea.

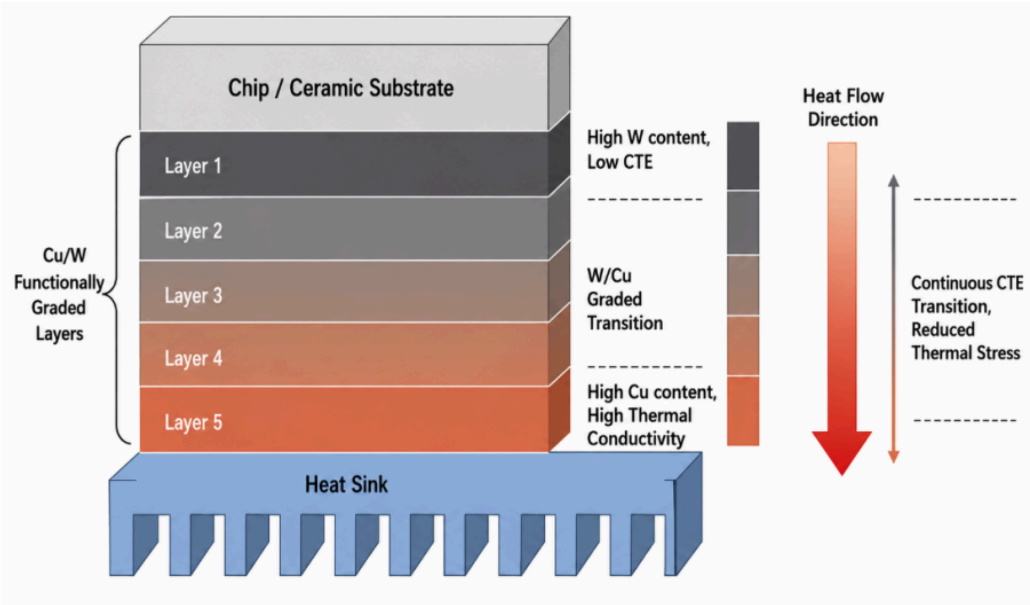

Figure 6. Schematic diagram of compositional design of Cu/W functionally graded material

3.2.2. Porosity gradient: optimizing the balance between thermal conductivity and mechanical properties

A porosity-gradient structure changes the local elastic modulus and provides strain-buffering capacity near brittle interfaces. Since pores may interrupt heat-transfer paths and reduce load-bearing capacity, the pore fraction should be limited during design. Pore locations shall be determined according to temperature and stress fields, instead of simply raising the overall porosity.

3.3. Element-doping modification and enhancement of thermal stability

3.3.1. Metal-element doping: improving wettability and promoting densification

Elements such as Ni, Co and Fe are commonly used as activated components in Cu/W composites. Moderate addition of these elements improves the wettability of liquid phase on tungsten particles and accelerates mass transfer at interfaces, which facilitates pore shrinkage and material densification. Such beneficial effects will not keep growing with higher doping content. Insufficient dopant leads to weak activation effects, while excessive addition may form impurity phases inside the microstructure, break the originally continuous copper heat-conducting channels and finally decrease thermal conductivity. The dosage of activated elements should be determined comprehensively on the basis of relative density, microstructure morphology and thermal conductivity.

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3.3.2. Non-metal-element doping: enhancing microstructure stability

Carbon-based reinforcements bring benefits beyond mechanical strength. For example, properly dispersed graphene can bridge local interfaces and improve load transfer [13]. Nevertheless, agglomeration or poor contact between reinforcements and the matrix will create new interfaces acting as thermal-resistance sites and crack-initiation sources. Therefore, its modification effect strongly depends on dispersion technology and interfacial conditions.

3.4. Composite-modification strategies and synergistic mechanism

For third-phase modification, it is necessary to evaluate whether performance gains outweigh the thermal losses caused by newly-formed interfaces. In the W-Cu-C system, carbon phases are introduced to optimize local interfaces. In the W-Cu-M system, elements such as Mo and Cr are adopted to regulate interfacial reactions and thermal-expansion behaviour. Thick reaction layers, second-phase segregation or interrupted copper conduction channels will impair thermal conductivity. The evaluation of composite modification should cover relative density, interfacial microstructure, thermal conductivity and thermal-cycle stability, rather than relying on a single room-temperature performance indicator.

4. Application and performance evaluation of Cu/W materials in electronic packaging

4.1. Thermophysical-property test methods and core evaluation indicators for Cu/W materials

The evaluation of Cu/W substrates for packaging should at least cover thermal conductivity, coefficient of thermal expansion (CTE) and stability after temperature cycles. Thermal conductivity reflects the capacity of heat transfer through substrates, while the coefficient of thermal expansion determines its matching level with chips and ceramic layers. The former can be obtained by the steady-state method or laser flash method, and the latter is generally measured by thermomechanical analysis [14]. When comparing different materials, the test temperature range, density and measurement direction should also be specified. Otherwise, the data cannot be directly compared.

4.2. Research on heat-dissipation performance and electronic-packaging adaptability of Cu/W substrates

4.2.1. Thermal-conductivity test: comparison between steady-state plate method and laser flash method

Copper content only represents the nominal composition of Cu/W composites and cannot fully determine their thermal-conducting performance. In the actual heat-transfer process, whether the Cu phase can form continuous channels inside the material carries greater importance. Even if two materials have similar copper content, one sample may exhibit obviously lower thermal conductivity owing to abundant pores, poor W-Cu interfacial bonding or Cu phase divided by tungsten particles. The tungsten phase itself is not the major heat-conducting channel. Its function lies more in reducing the thermal expansion of materials and maintaining the dimensional stability of substrates under temperature variation [12]. As shown in Figure 7, Cu/W heat sinks are usually placed between chips and radiators to receive and transfer heat generated by chips outwards.

DOI: 10.54254/2755-2721/2026.36974

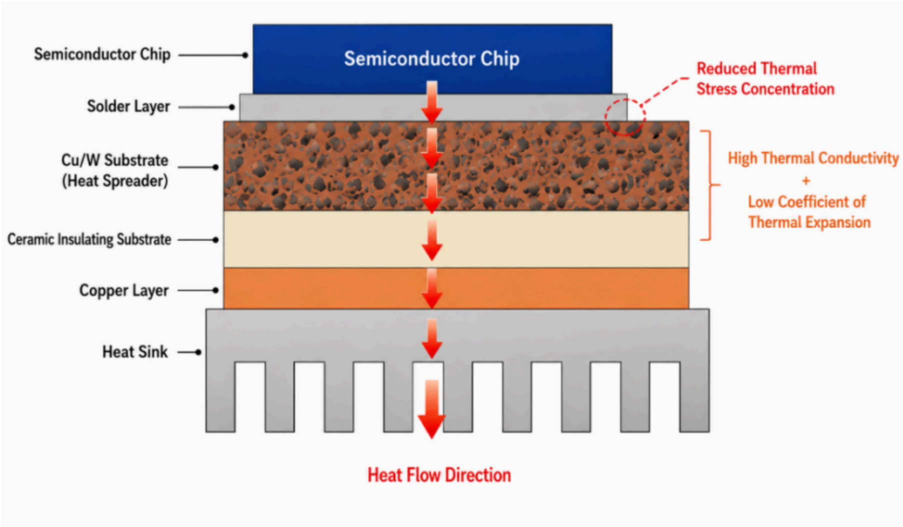

Figure 7. Schematic diagram of heat dissipation structure with Cu/W heat sink in power device packaging

4.2.2. Coefficient-of-thermal-expansion test: CTE variation under temperature cycles

The coefficient of thermal expansion decreases with rising tungsten content, yet this improvement is usually accompanied by fewer copper heat-conducting channels. Hence, the proper composition ratio shall be determined by both the allowable CTE window of packaged components and permitted thermal resistance, instead of pursuing the minimum thermal expansion coefficient. Temperature-cycle tests also need to pay attention to irreversible deformation or interfacial damage generated during heating and cooling.

4.3. Mechanical-property and reliability assessment of Cu/W substrates

4.3.1. Bending-strength and hardness tests

Substrates are subjected to bending, clamping and thermal stress during assembly and service. With few pores, homogeneous microstructure and favourable interfacial bonding, loads can be stably transferred between the two phases, and the bending strength as well as hardness will become more controllable. Hardness data alone are insufficient to judge packaging reliability. Fracture morphology and interfacial failure locations should also be taken into consideration.

4.3.2. Thermal-cycle fatigue-life analysis

Repeated heating-cooling cycles produce cyclic shear and tensile stress among Cu/W substrates, solders, ceramic substrates and chips. After the accumulation of thermal mismatch, cracks often initiate near pores, coating defects or interfacial reaction layers. Adjusting the W/Cu ratio, improving densification degree, controlling surface coatings and adopting gradient transition structures can reduce the amplitude of local stress [15].

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4.4. Application cases of Cu/W substrates in high-power devices

4.4.1. Power-amplifier packaging for 5G communication base stations

GaN or GaAs radio-frequency chips produce highly concentrated heat sources in base-station power amplifiers. When Cu/W materials are used as heat sinks or packaging bases, they can conduct heat and meanwhile restrict thermal-expansion mismatch with chips. Actual material selection still needs to combine chip size, bonding-layer thickness and operating temperature range.

4.4.2. Heat-dissipation substrates of IGBT modules for new-energy vehicles

IGBT modules suffer from long-term junction-temperature fluctuation and power cycles. The thermal transition layer for heat dissipation should rapidly spread heat and reduce the strain difference between chips and ceramic layers. Cu/W materials can serve as such transition layers. Whether their advantages can be maintained depends on interfacial bonding quality and thermal-resistance variation after thermal cycles.

4.5. Practical-application challenges and optimization directions of Cu/W substrates

Engineering-oriented limitations are mainly found in manufacturing and performance verification. Preforms with high tungsten content are sensitive to powder gradation, pore-channel connectivity and infiltration temperature window. The high hardness of tungsten increases subsequent machining cost. Meanwhile, systematic experimental data on complex power cycles and long-term airtight performance remain limited in published research. Table 2 summarizes typical properties and applicability of different fabrication or treatment routes. Follow-up research shall combine low-cost forming technology, controllable interfacial layers and device-level life tests, rather than merely optimizing the initial thermal conductivity of material specimens.

Table 2. Comparison of packaging properties of Cu/W alloys prepared by different processes

Material System	Preparation/Treatment Method	Thermal Conductivity / $W \cdot m^{-1} \cdot K^{-1}$	CTE Characteristics	Packaging Applications	Main Issues	References
W-15Cu	Infiltration	190–193.5	Relatively low	Heat sinks / packaging bases	Relatively long processing cycle	[12]
Cu/W	SPS	Above 200	Adjustable	High-density substrates	High equipment cost	[6, 11, 13]
Cu/W	Activated liquid-phase sintering	170–220	Relatively low	Low-temperature densification materials	Activating agents may reduce thermal conductivity	[5, 8]
Cu/W/Ni	Infiltration + Ni plating	180–210	Relatively low	Solderable packaging	Plating layer may increase thermal resistance	[5, 12]
Cu/W/Ni/Au	Surface composite plating	180–220	Adjustable	High-reliability soldered packaging	Relatively high cost	[5, 15]

DOI: 10.54254/2755-2721/2026.36974

5. Conclusion and prospect

The application value of Cu/W composites lies in the unique biphase coordination mechanism, in which the tungsten phase restricts thermal expansion and the copper phase constructs efficient heat transfer channels. However, the nearly immiscible characteristic of Cu and W phases has long been a key bottleneck restricting the densification and interfacial precision control of Cu/W materials. Among the existing preparation processes, the infiltration method is more suitable for fabricating Cu/W materials with high tungsten content and continuous skeleton structures. Hot pressing sintering and spark plasma sintering can effectively improve the densification degree of materials by applying external pressure, while conventional powder metallurgy boasts prominent advantages in production cost and large-size component machining. Activated element doping, surface plating treatment and gradient structure design can optimize the sintering performance, interfacial connection state and thermal stress transition effect of materials respectively, yet these modification methods may also lead to reduced thermal conductivity and increased manufacturing complexity. Targeting the application demands of 5G radio frequency devices and new energy vehicle power modules, future research should take the allowable thermal resistance and thermal expansion coefficient range of devices as the constraint conditions. It is necessary to establish a systematic and comprehensive evaluation system covering material preparation, interfacial bonding performance and thermal cycle service life, and further verify the performance consistency of large-size and batch-produced Cu/W components.

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