

Advancement of Graphene Thermal Interface Materials in Electronic Devices

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ABSTRACT

With the continuous innovation of modern electronic products, different materials can correspond to the performance of different electronic devices. However, the improvement of performance is often accompanied by thermal runaway, such as the explosive growth of chip and heat flux density. This paper explores the thermal properties of graphene and related materials. Due to its two-dimensional sheet structure, phonons have a high conduction thermal conductivity in the material. Based on this, this paper uses the literature research method and the summary method to conclude that graphene and its related materials have better prospects as thermal interface materials in high-tech applications such as electronic devices.

Keywords: Graphene, Thermal Interface Materials, Composite Materials, Graphene Films

1. INTRODUCTION

The electronic era has high requirements for heat dissipation, and graphene can effectively solve this problem. At the same time, graphene is a single-layer carbon atom structure separated from graphite. As a new type of nanomaterial, it has unique intrinsic properties. Its Young's modulus is 1100 GPa, the bond-breaking strength is 125 GPa, and the thermal conductivity is as high as 5300 W/m·K^[1]. Because of these advantages, it can become one of the materials with high performance. This paper will be described in three sections: the introduction of graphene, the heat dissipation characteristics of graphene composites and graphene films. This paper aims to summarize the different conclusions obtained from different experiments on graphene thermal interface materials by predecessors, find the application fields of different graphene thermal interface materials, and hope to provide help for finding new breakthrough points in the future.

1.1 Overview of Graphene Characteristics

Graphene has strong performance in the field of heat conduction. The heat conduction mechanism of graphene belongs to the phonon conduction mechanism. As a kind of crystal material, its heat conduction ability is much higher than that of non-crystalline materials. It benefits from the orderly lattice vibration in the ordered crystal space rather than disordered scattering. Moreover, graphene also has strong covalent bonds and a two-dimensional symmetric structure, which further enhances its heat conduction performance^[2]. Due to its excellent heat conduction properties, a variety of composite materials combined with graphene have been developed, broadening the path of graphene in heat conduction and having good prospects.

1.2 Problems of Graphene

The improvement in performance comes with a high cost. Due to strong anisotropy, its vertical thermal conductivity is poor while its lateral thermal conductivity is good, being at an extreme. At the same time, the thermal resistance between graphene sheets is large. Although single-layer graphene has strong thermal conductivity, the stacking of graphene in composite materials greatly weakens its thermal conductivity. Since composite materials are still in the development stage, this will have an impact on it. Graphene is also known for its high electrical conductivity. If a thermally conductive material that requires insulation needs to be made, high-cost insulating materials such as ceramics must be compounded, further increasing the cost. In addition, graphene begins to gradually oxidize and is eventually destroyed at 400 - 500°C in air, proving its limited stability at high temperatures. These disadvantages are exactly the problems that need to be overcome in current research. It is hoped that a solution can be found soon.

2. GRAPHENE-RELATED MATERIALS

2.1 Composite of graphene and traditional thermally conductive metal materials

Graphene has strong thermal conductivity, so it is compounded with other materials to explore how to further improve its thermal properties. Because the composite of graphene constructs a 3D graphene thermal conduction network, through the compounding of graphene with different materials, it demonstrates excellent thermal conduction performance and application potential in fields such as electronic devices. For example, the thermal conductivity of traditional thermally conductive materials is low. Combining nanosheets with graphene can improve the thermal conductivity with less material used. After experiments, a highly ordered brick structure is formed. Compared with single-layer graphene as a composite material, the orderliness is further enhanced, improving the thermal conductivity. It has a $28.8 \text{ W}/(\text{m}\cdot\text{K})$ in-plane thermal conductivity and a 124MPa tensile strength, demonstrating good processability and application potential [3]. At the same time, graphene can also be compounded with metal materials. In the traditional heat dissipation materials, the thermal conductivity of aluminum alloy is about $200 \text{ W}/\text{m}\cdot\text{K}$. Copper has a high cost and a large density, both of which are difficult to meet the requirements. The theoretical thermal conductivity of graphene is as high as $5300 \text{ W}/\text{m}\cdot\text{K}$, making it an ideal heat dissipation material [3]. As a heat dissipation material, graphene has a wide range of applications. In the field of electronic devices, high thermal management has become an essential part. After being combined with a copper composite heat sink, a composite material with high thermal conductivity, light weight, and the ability to withstand extreme environments has emerged. In the field of electronic devices, this composite material can reduce the thermal module by 18.6%. In the 5G field, it is 34% lower than the pure copper module. Similarly, at a working frequency of 28 GHz, it can maintain the temperature of the chip below 85 degrees. The Huawei White Paper further proves its long-term stability in 2023. There are also various preparation methods for this composite material, mainly including powder metallurgy, spark plasma sintering, chemical vapor deposition, and hybrid manufacturing technology. There are multiple methods converging into the hybrid preparation process, but this composite material also faces challenges [3]. Due to the strong van der Waals force between graphene and the large density difference between graphene and copper, it is difficult to achieve a relatively uniform dispersion. The dispersion strategies used in the current medium environment are divided into: solid-phase dispersion, liquid-phase dispersion, and solid-liquid interface-assisted dispersion. Through these methods, the dispersion has been improved in recent years. Deeply study the enhancement of metals and the performance of composite heat sinks by graphene in metal matrices, and strengthen the research and use of this composite material.

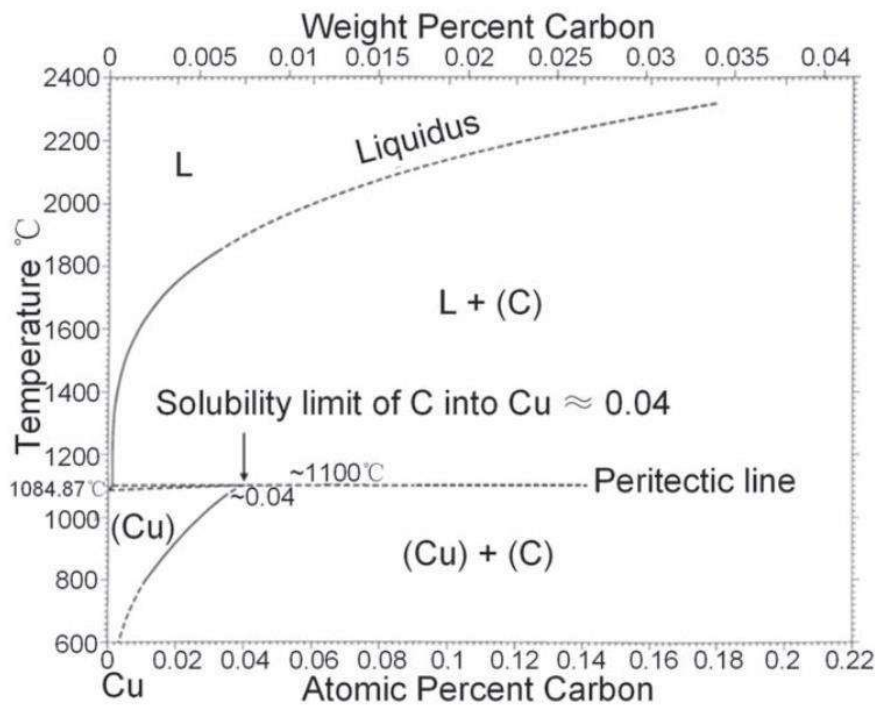


Figure 1. Cu-C Composite Phase Diagram [4].

2.2 Graphene Composite with Nanomaterials

As one of the relatively new materials, nanomaterials are being applied in a growing number of fields in people's lives today, and their thermal properties are relatively prominent. Due to their low-dimensional structure, they have extremely high thermal conductivity in specific directions, far exceeding that of traditional thermal materials such as metals and ceramics. In addition, nanomaterials have significant anisotropy, with good heat conduction along the growth direction. Combining nanomaterials with graphene has the potential to overcome the shortcomings of single components while compensating for each other's deficiencies. Graphene can be combined with nanomaterials of different dimensions. When graphene is combined with zero-dimensional nanomaterials, it can be dispersed between graphene layers to block interlayer stacking and reduce phonon heat dissipation. For example, when combined with silver nanomaterials, its thermal conductivity can exceed 1600 W/(m·K), with excellent thermal cycling stability, suitable for use in high-tech chips, and the cost can be controlled within a relatively acceptable range. When graphene is combined with one-dimensional nanomaterials, a three-dimensional thermal conduction network can be constructed, which not only significantly reduces the interfacial thermal resistance but also improves the material properties. This material is suitable for making flexible thermal conductive films due to its high heat dissipation efficiency and flexibility [5]. When graphene is combined with two-dimensional nanomaterials, it solves the problem of possible short circuits caused by its high conductivity while ensuring efficient heat dissipation. For example, after being combined with hexagonal boron nitride nanosheets, the thermal conductivity can be increased by nearly 800%, with excellent aging resistance and thermal stability, suitable for equipment environments that require insulation and efficient heat dissipation. The combination of graphene and nanomaterials can complement each other to overcome the original defect problems of both sides. With continuous breakthroughs in this application direction, this material is expected to better adapt to the heat dissipation requirements of more advanced electronic devices. It also has good development prospects in aerospace and military applications, becoming the mainstream research direction of new high-efficiency heat dissipation materials.

Table 1. Performance Improvements of Graphene Combined with Nanomaterials of Different Dimensions.

Composite materials	Dimension selection	Matrix material	Thermal conductivity before composite	Thermal conductivity after composite	Improvement range
Graphene and zero-dimensional nanoparticles	0Dcomposite	PMMA、epoxy resin、PVDF	0.2-0.5	0.8-3.0	2-8times
Graphene and carbon nanotubes	1Dcomposite	Polymers, flexible films	0.2-0.6	1.5-10	5-20times
Graphene and two-dimensional nanosheets	2Dcomposite	Polymers, ceramic matrix	0.3-0.8	3.0-30	10-40times

2.3 Graphene Membrane

Although graphene has good thermal conductivity, if we want to reflect its anisotropy in macroscopic materials, we can stack multiple graphene layers to form a graphene film. We can transform graphene or graphene oxide into a powder state and then further process it into a film. For example, we can use the CVD method, coating method, vacuum filtration method, self-assembly method, and spin coating method to fabricate graphene thermal films [3]. We can also add the graphene film to a metal plate. Through comparative experiments, it is found that the metal plate coated with the graphene film has improved thermal conductivity, indicating the good heat conduction properties of the graphene film. With the development of graphene material preparation and application technologies, since 2018, graphene-based thermal conductive film materials prepared from graphene or graphene oxide as precursors have witnessed rapid development. As the material with the highest known thermal conductivity, by utilizing the two-dimensional sheet structure of graphene and its easy film-forming characteristics, macroscopic graphene film materials with high thermal conductivity can be prepared, and their thickness can be adjusted from dozens of nanometers to hundreds of micrometers according to requirements, becoming the key material to solve the thermal management problems of high-performance electronic devices. The preparation of graphene thermal films essentially involves assembling graphene nanosheets with nanoscale thickness and micron-scale sheet diameter into macroscopicfilm materials and restoring them to a graphite-like crystal structure. It can be prepared by various methods. At the same time, graphene films prepared using different graphene precursors show significant differences in thermal conductivity, and the factors affecting thermal conductivity are also

significantly different, but their respective advantages and disadvantages are relatively obvious ^[6]. Therefore, it is necessary to further search for better methods. In addition, different graphene sizes also vary, all of which have an impact on heat conduction. Smaller graphene sheets generally have a higher specific surface area in most cases, resulting in more interface scattering and thus reducing the thermal conductivity, while larger graphene sheets are the opposite. Therefore, optimizing the size of graphene is also an essential step.

3. CONCLUSION

This paper explores the application promotion of graphene thermal interface materials and electronic devices, discusses several materials related to the thermal properties of graphene, and also discusses the advantages and disadvantages of these materials. Although graphene composites have excellent properties, there are significant obstacles in terms of cost and interfacial dispersion. Moreover, the performance of graphene films continuously weakens with the increase in stacking, which is also a major problem. Graphene has good prospects in the field of thermal interfaces, and in the future, we hope to precisely adjust the interfacial thermal resistance, control costs, and optimize the structure to break through the current obstacles and provide reliable technical support for the thermal management of the new generation of electronic devices ^[7]. Compared with previous studies, this paper lacks an understanding of graphene nanocomposites. We hope to broaden our research perspective through more in-depth research in the future, and also hope that scholars on related topics can conduct further research to promote the true transition of graphene thermal interfaces from the laboratory to engineering application.

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