

Research Progress of Graphene Thin Films for Heat Dissipation Applications in Electronic Devices

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Abstract: Owing to its superior thermal conductivity, graphene films excel in heat transfer and dispersion, enhancing the efficiency of electronic devices in dissipating heat. Various graphene-based composite materials are created by blending with other substances, catering to diverse needs. Currently, graphene's production process is well-established, with several composites performing well. Nonetheless, achieving widespread production and production of graphene, along with the effective management and refinement of interfacial thermal resistance, remains a challenge.

Keywords: Graphene Film; Electronic Devices; Heat Dissipation; Literature Review; Thermal Conductivity.

1. Introduction

The swift advancement in electronic technology has led to a gradual decrease in the size of electronic devices and a rise in their integration levels. Electronic devices in the working process will generate a large amount of heat, if not timely and effective heat dissipation treatment, the high temperature will seriously affect the performance, reliability and life of the device. In the past, the traditional heat dissipation materials, although the thermal conductivity is relatively good, but in the face of increasingly complex and high-density electronic devices, has been gradually unable to carry too much heat, which led to their gradual elimination. Heat dissipation has become a key factor in restricting the performance and reliability of electronic devices. The search for new and efficient heat dissipation materials has become a hot spot in current research, so it is necessary to explore the potential application of graphene film in the heat dissipation of electronic devices. Graphene films are characterized by their excellent thermal conductivity (up to 5300 W/mK), which is in the range of 4840 ~ 5300 W-m-1-K-1 at room temperature for ordinary single-layer graphene [1,2]. The high thermal conductivity of graphene film enables it to quickly conduct the heat generated by electronic devices, greatly reducing the operating temperature of the devices, thus improving performance and extending service life. In addition, the thinness and lightness of graphene films make them unique in miniaturized electronic devices. By integrating graphene films into the heat dissipation system of electronic devices, the heat dissipation efficiency can be significantly improved to ensure the stability of the devices under high load operation [3]. The goal of this review is to systematically sort out the research progress in the field of graphene thin films for heat dissipation in electronic devices, including the preparation technology of graphene thin films, the testing and evaluation methods of heat dissipation performance, and the application cases in real electronic devices.

2. Basic Properties of Graphene Films

Graphene thin films, two-dimensional in nature, are made up of a singular carbon atom layer with a distinct hexagonal honeycomb lattice configuration. This structure features a

hexagonal lattice of carbon atoms, created by sp² hybridized orbitals, where each atom is covalently linked to three adjacent carbon atoms [4]. This planar honeycomb structure gives graphene extremely high in-plane strength and flexibility. The theoretical specific surface area of a single layer of graphene is about 2630 m²/g, making it a powerful performance role in heat transfer and surface reactions. The thickness of graphene is only the diameter of one carbon atom (about 0.34 nm), which achieves absolute lightweight in practical applications. And the thermal conductivity mechanism of graphene film mainly relies on phonon (lattice vibration) conduction in its lattice. Among other things, phonon conduction is in graphene, where heat is conducted mainly through the propagation of phonons. This high thermal conductivity in graphene is largely due to its rapid phonon velocity and extended phonon mean free range [5].

Graphene scatters fewer phonons, which allows phonons to transfer heat over longer distances for efficient heat transfer. Graphene has an extremely high in-plane thermal conductivity, with a theoretical value of up to 5000 W/m-K, due to its strong carbon-carbon covalent bonds and high phonon propagation speed. By optimizing the arrangement and interfaces between graphene layers, its overall thermal conductivity can be improved to some extent. Graphene's high thermal conductivity facilitates rapid and efficient heat transfer, making it suitable for heat dissipation in high power density electronic devices. Graphene exhibits excellent thermal stability at high temperatures, stabilizing up to about 400-500°C in air [5] and even higher in an inert atmosphere [6]. Graphene has a very low coefficient of thermal expansion, which means that graphene has minimal dimensional changes during temperature changes, helping to maintain the structural stability of the device.

3. Research Progress of Graphene Thin Film Heat Dissipation Technology

The thermal conductivity of graphene thin film is measured by Raman spectroscopy, time-domain thermal reflection, and transient planar heat source method. At ambient temperatures, the thermal conductivity of standard single-layer graphene ranges from 4840 to 5300 W-m-1-K-1, whereas the number of layers of graphene is closely related to the thermal

conductivity, which tends to decrease with the increase of the number of layers. The interlayer thermal conductivity of multilayer graphene is relatively low because of the weak van der Waals forces between the layers, resulting in high scattering of phonons during interlayer transport. The presence of defects significantly reduces the thermal conductivity of graphene, and cavity defects and point defects can reduce the thermal conductivity of graphene to 400 W·m⁻¹·K⁻¹ and below about 30% of the original thermal conductivity, respectively. In addition, the edge roughness and shape of graphene have a significant effect on its thermal conductivity, and the thermal conductivity of graphene with smooth edges is higher than that of graphene with rough edges [1]. Thermal diffusion coefficient is an important parameter to measure the rate of heat transfer in materials. The high thermal diffusion coefficient of graphene film enables it to disperse heat quickly and evenly to prevent localized overheating. In practice, the thermal performance of graphene films is also affected by its interfacial thermal resistance with other materials, film thickness, number of layers, defects, and other factors. It is shown that the thermal performance of graphene films can be further improved by optimizing their preparation process and structural design. By modeling the heat sink simulation, it is found that the main factors affecting the performance of the graphene thin film heat sink are the input power of the power device and the area ratio of the contact surface between the power device and the heat sink. The heat dissipation performance changes significantly as the input power increases and the area ratio decreases. By optimizing the BP neural network model, it is found that the network performance is optimal when the number of neurons is 14 and the number of hidden layers is 4. Its experimental results show that the heat sink coated with graphene film has 4.12% higher thermal performance than the heat sink without graphene film [7]. The heat dissipation effect of graphene varies when it is coated in different positions of the heat pipe heat sink, with the best heat dissipation effect of fully coated graphene [8]. The flexibility and high thermal conductivity of graphene film are utilized to design heat sink structures adapted to different shapes and sizes, such as flat plate, finned, and curled. Combining the hybrid structure of graphene film and conventional heat dissipation materials, along with alternately arranged multilayers of graphene and high thermal conductivity fillers, the mechanical strength and stability can be enhanced while maintaining high thermal conductivity. Design and preparation of planar heat sink devices based on graphene/bismuth antimony tellurium composite thermoelectric films and their cooling performance. In the experiment, the addition of graphene resulted in a significant enhancement of the electrical transport properties of the composites, which enhanced the carrier concentration and accelerated their mobility, thus improving the thermal performance [9]. Graphene films play an important role as thermal interface materials (TIM) in heat dissipation of electronic devices. Interfacial thermal resistance is a key factor affecting heat transfer efficiency. The thermal resistance at the interface between graphene film and metal or semiconductor significantly affects the overall thermal performance. The interfacial thermal resistance can be significantly reduced by optimizing the interfacial contact quality and interfacial materials [10]. Interfacial materials with good compatibility with graphene films, such as highly thermally conductive polymers, metal films, or carbon-based materials, were selected to enhance the interfacial thermal

conductivity.

4. Investigation into the Heat Efficiency of Composites Made from Graphene

Graphene-based composites merge graphene's superior thermal conductivity with that of other matrix substances, markedly boosting their thermal conductivity. They are prepared by solution mixing method, melt mixing method, solution coating method, and in situ polymerization method. And the thermal conductivity of graphene-based composites depends on the content of graphene, the state of dispersion and the nature of matrix materials. Elevated graphene content typically boosts their thermal conductivity substantially. However, too high graphene content may lead to a decrease in the mechanical properties of the material or even processing difficulties. Uniform graphene distribution within the matrix is vital for enhancing thermal conductivity. A good dispersion state can form a continuous heat conduction network and reduce thermal resistance. The thermal conductivity of the matrix material also has an important influence on the overall thermal conductivity of the composite material. Selection of highly thermally conductive matrix materials can further enhance the thermal conductivity of composites. On a graphene-aluminum composite cold plate based on graphene, the thermal conductivity of graphene heat sinks with different thicknesses was experimentally tested under different power consumption conditions. Experimental results show that graphene can significantly improve the thermal conductivity of aluminum alloy, especially when 2 mm thick graphene heat sink is pasted on the surface of aluminum alloy, the thermal conductivity reaches the best, reaching a thermal conductivity of 360-370 W/(m·K), and it weighs only 66.5% of the weight of a 6 mm thick aluminum plate [11]. It shows that the thermal conductivity of this type of composite cold plate has an important influence. In the composite films containing montmorillonite (MMT), reduced graphene oxide and polyvinyl alcohol (PVA). It is mainly concluded that the graphene oxide (GO) prepared in a low-temperature water bath helps to improve the thermal conductivity of reduced graphene (rGO); while the MMT layer plays a role in effectively preventing the agglomeration of GO during the reduction process, which contributes to the orderly arrangement of rGO in the composite film, and thus improves the thermal conductivity. Hydrogen-bonding between the binary filler of MMT/GO and the PVA matrix improves the interfacial bonding, which further enhances the interfacial thermal resistance and reduces the interfacial thermal resistance. The interfacial thermal resistance was reduced to further enhance the thermal conductivity of the composite film. The highest thermal conductivity (66.4 W/(m·K)) was achieved for the composite film when the mass ratio of MMT to GO was 2:1 and the mass fraction of the binary filler was 12%, which was a significant improvement compared to pure PVA. It was finally concluded that the thermal conductivity of the polymers was significantly improved using MMT and rGO by adjusting the structure and composition of the composite films [12]. The preparation of polypropylene (PP)/graphene composites and the effects of electrical, mechanical, thermal, crystalline and rheological properties. So the incorporation of graphene into PP composites can enhance their properties to different degrees. which can

improve the overall thermal conductivity [13]. Graphene/polymer composites are widely used in high-performance computers and electric vehicle battery management systems [14]. Graphene/polysiloxane composites have a strong stability and thermal conductivity in mechanical properties [15]. In terms of preparation methods, the films prepared by electrodeposition [16] and electrochemical method [17] both contribute to the improvement of thermal properties and help to increase the thermal efficiency of electronic devices. Through the above preparation methods, thermal conductivity optimization and practical application cases, graphene-based composites show great potential for heat dissipation applications in electronic devices. Future research will continue to focus on improving the properties and processability of graphene-based composites to meet the evolving needs of practical applications.

5. Challenges and Prospects of Graphene Thin-Film Heat Dissipation Technology

Uniform graphene distribution within the matrix is vital for enhancing thermal conductivity [18], the high manufacturing cost makes it difficult to realize large-scale production. And the homogeneity and purity have an important effect on its thermal conductivity. The possible introduction of impurities and inhomogeneities during the preparation process can significantly degrade its properties. The interfacial thermal resistance between graphene and matrix material is a key factor affecting the thermal conductivity of composites. How to effectively reduce the interfacial thermal resistance still needs further research. Uniformly dispersing graphene in the matrix material is a technical challenge. And graphene tends to agglomerate, resulting in inhomogeneous properties of composites. Thermal conductivity measurements, the accuracy of which also has some limitations. The thermal conductivity and thermal diffusion coefficient of the reduced graphene oxide and polypropylene composite samples prepared by melt injection molding method were measured, and serious anisotropy in the thermal conductivity was found. According to the progress of measurement research, the current problems in the measurement of thermal conductivity of graphene and its composite materials are pointed out. Graphene materials have at least one dimension in the nanometer range, the original thermal conductivity measurement method is not fully applicable to the measurement of graphene, now need to be combined with optical and microelectronic technology (laser flash-Raman spectroscopy and electrothermal microbridge method) in order to carry out effective and more accurate measurement. Currently there is a lack of direct and accurate methods to measure the interfacial thermal resistance. The commonly used indirect measurement methods (e.g., time-domain thermal reflectometry) have some limitations [19].

6. Conclusion

Develop low-cost and high-efficiency graphene preparation techniques. Improvement of quality control techniques during graphene preparation to ensure high purity and homogeneity of graphene output. Development of graphene-based composites with multifunctionality has great prospects. Graphene-based composites are promising for heat dissipation applications in high-power electronic devices (e.g.,

CPUs, GPUs, LEDs, etc.) and flexible electronic devices, and are expected to significantly improve the heat dissipation efficiency and reliability of the devices. In the field of energy, electric vehicle battery management and thermoelectric materials possess a wide range of uses. By overcoming technical challenges and improving measurement and characterization methods, graphene-based composites hold great promise for future research and applications. Continuous innovation and technological advancement will drive its impact and role in various fields.

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