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Review on the Design and Performance Optimization of Acoustic Equipment Assisted by Graphene films

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Abstract. Graphene is widely used in 5G devices, wearable flexible electronic devices, sensors and other fields due to its superior electromagnetic shielding ability, low thermal conductivity and high sensitivity piezoresistive characteristics. This paper focuses on the application of graphene films in the field of acoustics. Graphene films can contribute to the chain-based industrial development of materials, processes- applications in the field of acoustics, but currently, the industrialization is in its infancy. This kind of materials have the potential breaking through the technical design limit of traditional acoustic devices and equipment. This paper adopts the research method of literature analysis. This paper summarizes the current state of applications of graphene films, as well as their future development directions. It can be concluded that graphene films are currently widely used in flexible electronics, high-sensitivity sensors and new energy fields. Its future development focuses on breakthroughs in low-cost mass production technologies and multi-functional integration. In addition, in the field of acoustics, its ultra-thin and high-strength characteristics have been applied to the development of high-frequency response speaker diaphragms, significantly enhancing the clarity of sound quality and the durability of equipment. Moreover, with the optimization of material processes, its application prospects in miniaturized acoustic devices and smart wearable auditory devices are broad.

Keywords: graphene, graphene films, acoustic, application of graphene films

1. Introduction

Since the discovery of graphene in 2004, researches on graphene and graphene films has attracted increasing attention from all walks of life and has made some considerable progress in recent years. Lin et al. [1] used nanoarchitectonics to design a hyperbolic paraboloid(HyPar)diaphragm by controlling and optimizing nanolayers GO and PAN Youdaoplaceholder, they successfully developed a scalable spray coating method to assemble a new type of nanostructured material, the GO/PAN diaphragm has great potential in sustainable next-generation acoustic devices.Zhang et al. [2] produced hybrid graphene-Au nanofilms through a one-step layering process. The resulting metal films have better flexibility and radio frequency functions compared with those fabricated by traditional methods [3,4]. The innovative design and materials have a significant impact on flexible wireless technology for radio frequency communication. Lee et al. [5] synthesized monolayer and multilayer graphene sheets by CVD and used them as diaphragms for silent speakers.After

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measuring the frequency response,they determined that the larger the area of the diaphragm,the greater the sound pressure of the frequency response. They proposed an optimized solution for the best graphene membrane configuration for future silent speaker applications. This article mainly focuses on three aspects: a brief introduction to the concept of graphene films, some important research findings on graphene films in the field of acoustics, as well as the technical barriers and future development directions of graphene films in the field of the acoustic. This paper adopts the research method of literature analysis. This paper reveals the acoustic mechanism of graphene low-dimensional materials, and points out some directions for graphene films to facilitate the chain industrial development of materials - processes - applications in the field of acoustics and break through the technical design limits of traditional acoustic devices and equipment.

2. What is a graphene film

Over the past two decades, two-dimensional materials have been attracting the research interest of many scientists, and graphene is one of the most promising candidate materials in the high-frequency application field so far [6]. In recent years, graphene has played a significant role in fields such as integrated circuits, aerospace, and sensor communications due to its extremely high electron mobility ($>2\times10^5$ $cm^2\cdot V^{-1}\cdot s^{-1}$), superior mechanical strength, and excellent electromagnetic shielding capability. Graphene is an allotrope of carbon,where carbon atoms are bonded by sp^2 hybridization to form a monolayer hexagonal honeycomb lattice of graphene. This crystal structure can be utilized to derive and construct graphene quantum dots, fullerenes (C60)and so on. One of the mainstream preparation methods for graphene films is Chemical Vapor Deposition (CVD). The CVD method achieves the layer-by-layer controllable growth of monolayer graphene through the catalytic cracking of carbon source gases (such as methane) on the surface of high-temperature metal substrates (such as copper and nickel), and its lattice mass is closed to that mechanically exfoliated graphene. Copper foil has become the mainstream substrate due to its low carbon solubility, and highly uniform monolayer graphene can be obtained through the surface self-limiting growth mechanism [7].

3. The application of graphene films in the field of acoustics

In the technological transformation where the miniaturization of acoustic devices and the demand for high fidelity coexist, Lin et al.[1] proposed an expandable spraying method to fabricate GO/PAN acoustic diaphragms and used self-assembled nanoarchitecture to manufacture lightweight acoustic hyperbolic parabolic (HyPar) films. After analysis and material characterization, it was shown that The GO/PAN separator has a lower density and a higher storage modulus, and it is 15 times thinner and 8 times lighter than commercial banana pulp separator. This product not only improves the acoustic performance but also takes into account the cost-effectiveness of the diaphragm in the subsequent large-scale production process of application.

Lee et al.[8] employed monolayer and multilayer graphene sheets synthesized through chemical vapor deposition as charged diaphragms in electrostatic speakers, paired with indium tin oxide thin-film electrodes to generate Coulomb forces. Since the charge density of ML-G is higher than that of SL-G, when SL-G and ML-G are used as diaphragms, ML-G has better decibel performance in classic speakers. They confirmed through frequency response tests that the performance variation depends on the area of the ML-G separator. The larger the diaphragm area is, the greater sound pressure of the frequency response will be, and the larger the volume of air it drives to vibrate will be. Therefore, the electrostatic graphene speaker using ML-G diaphragms is superior to the

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electrostatic graphene speaker using SL-G diaphragms, and the larger the diaphragm area, the better the performance. This research provides critical size engineering criteria for the design of miniaturized acoustic devices.

4. Technical barriers and future research and development directions in other fields

4.1. Main technical barrier 1: environmental stability needs to be improved

In order to induce the thermoelectric effect on graphene for temperature sensing, it is necessary to connect graphene materials with two different Seebeck coefficients to form nodes. [9]. That is, different P-type and N-type chemical doping of materials is carried out on the surface of graphene(adjusting the type and concentration of carriers)..However, the dopant materials used in it are mostly unstable when exposed to air or solvents. Coupled with the presence of a large number of water molecules and oxygen in the air, these undoubtedly hinder the application of graphene films in flexible and wearable devices. [10,11] Regarding this issue, Lim et al. [12] provided a p-n junction method for fabricating monolayer graphene on a polymer substrate, that is, combining ultrathin Al_2O_3 with graphene p-n junctions to prepare flexible transparent thermocouples. After modulate oxygen plasma treatment on the monolayer graphene grown by CVD, they obtained p-n junctions through a partial coating of thin PEI. The experimental result is that the obtained thermocouple has a relatively high Seebeck coefficient, and the change of the Seebeck coefficient within 1028 days is almost negligible. Zhang et al.[13] fabricated a multifunctional PDMS/GrF@PPy by introducing polypyrrole nanowires between GrF and PDMS using GrF@PPy as reinforcement and PDMS as the polymer matrix. This method of anchoring the microenvironment at the interface of polypyrrole nanowires modified foam graphene improves the tensile strength, Young's modulus, electrical conductivity and thermal conductivity of PDMS/GrF@PPy composites. Both were higher than those of PDMS/GrF composites (showing excellent Joule heat and NIR radiation de-icing efficiencies of 82.9% and 55.7% respectively after the 500th tensile cycle). Therefore, studying surface encapsulation technologies (such as atomic layer deposition of alumina) or composite flexible substrates (such as PDMS) can enhance the wet heat resistance and mechanical durability of graphene films materials during applications.

4.2. Main technical barrier 2: due to the influence of some factors during the CVD preparation process on the thin film

The excellent mechanical properties of graphene result from the sp^2-hybridized strong covalent bonds in its two-dimensional honeycomb structure, which is both flexibility and resistant to fracture. The atomic-level dense arrangement and the synergistic effect of chemical bonds make it a highly promising ultra-light mechanical material. This gives the original graphene film a relatively good breaking strength, but the drawback of being prone to tearing after stretching and bending is not conducive to its application. Huan et al. [14] fabricated two-dimensional closely arranged micron-sized high-quality graphene sheets by optimizing the CVD process, and achieved multi-layer compact stacking by using the substrate repeat transfer method, constructing nanostructured films with both electrical conductivity and mechanical flexibility, breaking through the bottleneck of traditional graphene films being prone to tearing. Guo et al. [15] found through the adjustment of the growth time, growth temperature and total pressure of graphene films during the CVD process that the edge (vertex area) of the hexagonal etched holes formed by graphene during the growth process

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was the main site for crack initiation. This pressure-dependent defect suppression effect provides a key process optimization path for the preparation of low-defect graphene films.

Secondly, the introduction of impurities on the substrate surface also adds considerable challenges to the preparation of pure graphene film products. Incomplete removal of residual oxides or organic contaminants from the surface of metal substrates (such as copper) causes defects to form when graphene is grown . Jang et al. [16] innovatively developed an impurity adsorption and transfer technology based on ultraviolet-activated silica substrates, breaking through the bottleneck of impurity residue in the traditional process through a two-step transfer strategy. During the initial transfer stage, they use ultraviolet treatment to induce the formation of hydroxylated active sites on the surface of the SiO_2 substrate, selectively capturing contaminants on the graphene surface through strong van der Waals forces. After the secondary transfer to the target substrate, an atomic-level clean interface is achieved. This improved wet transfer technology helps eliminates impurities at the interface during the CVD thin film preparation process, better demonstrating the importance of interface purity for achieving optimal performance.

4.3. The main future application research directions in other fields

Graphene films, with their unique physical properties, have demonstrated multi-dimensional application potential in fields such as electrical conductivity, optics, and mechanics. In terms of conductivity , its extremely high carrier mobility makes it a core material for flexible electronic devices such as transparent electrodes for foldable touch screens, highly sensitive biosensors, and efficient micro supercapacitors, significantly enhancing the response speed and energy density of electronic devices. In terms of optical properties, monolayer graphene has a visible light transmittance of 97.7% and is conductive. It is used in dynamic dimming of smart Windows and ultra-thin solar cells, achieving a dual breakthrough in photoelectric conversion and visual transparency. In terms of mechanical properties , its tensile strength reaches 130 GPa (about 200 times that of steel) and it has super flexibility. It can be used as a blow-resistant circuit substrate for wearable devices and even as a driving material for artificial muscles, promoting the lightweight and high-strength structural materials.

5. Conclusion

Because of the excellent properties of graphene, its applications have been of great interest since its discovery in 2004. The laboratory preparation of graphene marks the beginning of the study of two-dimensional materials and propels the convergence of condensed matter physics, materials science and electrical engineering. With its disruptive properties of ultra-thinness, high conductivity and toughness, it reshapes the technological boundaries of electronic devices, new energy and biomedicine, accelerates cross-innovation in physics, chemistry and engineering, and promotes global industrial upgrading. This article mainly introduces the applications of graphene and graphene films. By analyzing the research discoveries and applications in this field in recent years, as well as the main technical barriers in the preparation process, it also looks forward to the multi-dimensional application prospects of graphene. This research focuses on the application of graphene films in acoustics. The article perspective is limit, and it is that the field can be further expanded in the future.

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