Opportunities and Challenges of Biomass-based Electromagnetic Shielding Materials

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Biomass with its abundance, renewability, and processability has been extensively studied and utilized for developing electromagnetic interference (EMI) shielding materials as an alternative to non-renewable metal-based EMI shielding materials. This editorial briefly discusses biomass and EMI materials, emphasizing the natural advantages of biomass for EMI shielding materials and current limitations. Finally, future research directions and challenges are predicted, providing insights to promote the development of biomass-based EMI shielding materials.

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Why Develop Electromagnetic Shielding Materials?

The development of EMI shielding materials is an urgent requirement for the advancement of modern electronic technology. With the widespread application of fifth-generation mobile communications, the Internet of Things, and high-speed computing devices, the EMI environment has become increasingly complex and seriously affects the operation accuracy of devices, data security, and even human health. High-performance EMI shielding materials may suppress electromagnetic wave propagation, prevent inter-device interference, and ensure reliable operation of precision electronics. As electronic devices evolve toward wider frequencies and miniaturization, EMI shielding materials must meet the increasingly demanding requirements for lightweight design, flexibility, and multifunctionality. The innovative development of such materials helps improve the overall performance of electronic products, extend equipment longevity, and provide crucial technical support for emerging technologies. Continuous research on advanced EMI shielding materials not only mitigates electromagnetic pollution but also ensures the creation of safer and more reliable electronic environments. However, conventional shielding materials face significant limitations, including excessive weight, limited flexibility, and complex fabrication processes. These materials perform poorly in terms of sustainability and largely rely on non-renewable resources. Biomass provides compelling advantages, including renewability, biodegradability, and environmental compatibility, which align with sustainable development goals and open new possibilities for the future of EMI materials. Through optimized structural design and developing advanced processing techniques, biomass-based EMI shielding materials that integrate high performance with environmental sustainability represent a promising strategy for overcoming current technological limitations.

Advantages and Disadvantages of Biomass-based Electromagnetic Shielding Materials

Biomass-based EMI shielding materials have garnered significant attention due to their unique sustainability and functional characteristics, with their primary advantages manifesting in the following four aspects. First, they exhibit exceptional environmental compatibility. Biomass encompasses renewable resources, including cellulose, chitin, and lignin, derived from agricultural waste (*e.g.*, straw and rice husks) and marine byproducts (*e.g.*, shrimp and crab shells). Biomass materials exhibit significantly lower lifecycle carbon footprints than traditional petroleum-based materials (Cheng *et al.* 2025) and complete biodegradability, thereby minimizing environmental pollution from waste EMI shielding materials. Second, they possess unique structural advantages. Natural biomass exhibits sophisticated microstructures, including hierarchical pore architectures and fibrous networks. For instance, wood features anisotropically oriented pores and three-dimensional interconnected networks composed of cellulose nanofibers. These unique structures create ideal interfaces for multiple electromagnetic wave reflection and absorption. Recent studies demonstrate that carbonized biomass maintains structural integrity while achieving sufficient conductivity (Zhao *et al.* 2021). The third advantage is they have excellent mechanical properties. Biomass-based materials demonstrate substantial mechanical strength and flexibility, rendering them ideal for flexible EMI shielding applications and wearable electronics requiring repeated bending. Finally, they have superior modification potential. The abundant functional groups of the biomass surface (such as hydroxyl and amino groups) facilitate functionalization and modification. Integration with nanomaterials, such as MXene and graphene, facilitates constructing synergistically enhanced conductive networks. Related research (Liang *et al.* 2020) shows that EMI shielding materials prepared from carbonized biomass can achieve shielding effectiveness of 40 to 60 dB in the X band (8.2 to 12.4 GHz).

Despite their advantages, biomass-based EMI shielding materials face several practical challenges. First, biomass is naturally insulating, requiring either high-temperature carbonization (> 600 °C) or high-loading conductive fillers to achieve effective EMI shielding. These processing approaches increase energy consumption and may compromise natural porous structures, resulting in mechanical property degradation. Second, biomass exhibit limited environmental stability. For instance, cellulose's surface hydroxyl groups make it moisture-sensitive, severely limiting long-term performance in harsh environments. Finally, there are certain bottlenecks in large-scale production. For instance, nanocellulose extraction involves energy-intensive mechanochemical processing that requires a subsequent modification process. Most current preparation methods remain at laboratory scale, insufficient for industrial-scale manufacturing requirements.

Potential and Challenges

Growing global interest in biomass resources and EMI shielding materials presents both substantial opportunities and challenges for biomass-based EMI material development. Conventional metal-based shielding materials face limitations, including limited biodegradability and high energy requirements. Developing EMI shielding materials based on biomass resources (*e.g.*, straw, rice husks, and sugarcane bagasse) enables high-value biomass utilization while supporting sustainable development goals. Biomass exhibit inherent porous architectures and tunable surface properties, providing distinct advantages for designing efficient electromagnetic wave absorption structures.

Their inherent flexibility and biodegradability make them particularly suitable for emerging applications, including flexible electronics.

However, the advancement of biomass-based EMI shielding materials encounters substantial challenges. To address the shortcomings mentioned above, it is essential to develop biomass-based EMI shielding materials that meet practical application requirements. Future research directions should include the development of green modification technologies to enhance the conductivity of biomass materials through green processes; the design of multi-level structures to improve broadband absorption performance; the development of new packaging technologies to enhance environmental stability; and the establishment of standardized raw material systems to develop low-energy continuous production processes. Furthermore, comprehensive life cycle assessments must ensure sustainability from raw material acquisition to end-of-product disposal. Systematically addressing these technical challenges will enable the industrialization of biomass-based EMI shielding materials and provide sustainable solutions for the industry.

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