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Review

A review on laser-induced graphene in flexible energy storage: From materials selection to biomedical applications

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ABSTRACT

Laser-induced graphene (LIG) has emerged as a promising alternative to reduced graphene oxide (rGO), significantly impacting biomedical engineering, particularly in energy storage for medical devices. While existing reviews primarily focus on LIG properties and sensor applications, this review examines LIG's potential as a flexible energy storage electrode for biomedical devices such as wearables and implants. This paper explores LIG from its accidental discovery to its current applications, highlighting its potential for end-user applications. It begins with a historical overview and discusses the challenges frequently faced in energy storage for biomedical applications, emphasizing the need for efficient, reliable solutions and the demand for miniaturized, flexible products. The review delves into the science of LIG, including its unique production methods and material properties, and compares it with traditional graphene, providing a competitive analysis. It then examines how LIG can be used as an electrode material in energy storage devices for wearables, implants, and drug delivery systems. Additionally, the transformative impact of LIG on drug efficacy, device performance, patient safety, and treatment outcomes are discussed. The paper also addresses the challenges of scaling up production, technical integration, and navigating the regulatory landscape. With its promising properties and performance, LIG shows potential as a key component in next-generation self-charging energy storage systems, offering transformative solutions for the healthcare sector.

1. Introduction

1.1. Historical context and modern challenges

The pursuit of advanced energy storage solutions with groundbreaking discoveries has been one of the fundamental studies in biomedical innovation in the journey of landscape evolution and technology advancement. In the past, the integration of energy storage technologies into biomedical applications was driven by the necessity of power sources for biomedical devices, such as pacemakers [1,2] and defibrillators [3]. These biomedical products especially implants require compact, long-lasting, and reliable power sources. The integration of power sources in a medical device begins with critical work back in the mid-20th century when the first implantable pacemaker was invented. This pacemaker was relying on nickel–cadmium (NiCd) cells that could possess limited lifespans, and it would require frequent recharge as short as once a month [4]. Hence, this drawback drives the search for a more sustainable and efficient energy storage solution.

As biomedical sector advances, an invisible pressure is contributing to drive the energy storage research extending to the next level of technology. In this modern era, society has witnessed a paradigm shift in the convergence of digital technologies with medical science. This phenomenon leads to the emergence of more sophisticated biomedical devices such as wearable health monitors (cardiovascular status [5,6], glucose level [7,8], blood oxygen level [9], pressure [10–13], and temperature monitoring [14,15]) and implantable drug delivery systems [16–20]. These advancements lead to a new set of challenges and requirements for energy storage solutions in terms of energy density,

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