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MINI REVIEW

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Innovative applications of 3D-printed nanomaterials in the development of next-generation smart devices

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ABSTRACT

Next-generation smart devices have been made possible by the combination of nanomaterials and 3D printing technology. High surface area, superior electrical conductivity, and remarkable mechanical strength are just a few of the special properties of nanomaterials that make it easier to create sophisticated, multipurpose devices with improved performance. Researchers have developed a number of cutting-edge applications, such as flexible wearable electronics, high-performance sensors, and energy storage systems, by leveraging the accuracy and versatility of 3D printing. This mini-review highlights notable advancements in the use of 3D-printed nanomaterials in a variety of industries, with a focus on renewable energy, healthcare, and environmental monitoring. Along with discussing potential future developments for hybrid materials and next-generation fabrication techniques, it also tackles the issues of material compatibility, scalability, and device reliability. The combination of 3D printing and nanotechnology has the potential to completely transform the smart device market, lead to new developments in customized electronics, and more.

KEYWORDS

3D printing; Nanomaterials; Smart devices; Wearable electronics; Advanced sensors; Energy storage; Biomedical applications; Flexible electronics; Additive manufacturing; Multifunctional materials

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Introduction

3D printing technology combined with cutting-edge nanomaterials has paved the way for the creation of next-generation smart devices. Because of their special qualities, which include a high surface-to-volume ratio, remarkable mechanical strength, and superior electrical and thermal conductivity, nanomaterials are pushing the boundaries of material performance [1,2]. When paired with 3D printing's adaptability, these materials allow for the creation of intricate, multipurpose, and highly customized devices that were previously impossible to achieve using conventional manufacturing techniques. By building things layer by layer from digital models, 3D printing, also known as additive manufacturing, gives users exact control over the final product's geometry and structure. Scientists have developed new classes of smart devices with improved capabilities by adding nanomaterials to the printing process. These include biomedical implants, wearable sensors, flexible electronics, and energy storage systems [3]. Along with being more compact and effective, these gadgets can also do things like monitor in real time and react adaptively to external stimuli. Healthcare, consumer electronics, aerospace, and environmental monitoring are just a few of the industries that stand to benefit greatly from this combination of 3D printing and nanomaterials. Wearable technology has been transformed, for instance, by the creation of flexible biosensors utilizing graphene-based nanomaterials [4,5].

Types of Nanomaterials Used in 3D Printing

The use of nanomaterials in 3D printing has led to new possibilities for creating cutting-edge smart devices with improved functions. Due to their distinctive electrical, mechanical, and thermal characteristics, these nanomaterials significantly enhance the performance and versatility of printed parts [6]. Below are several important categories of nanomaterials employed in 3D printing:

Carbon-based nanomaterials

Carbon nanomaterials, including graphene, graphene oxide (GO), and carbon nanotubes (CNTs), are commonly used for their outstanding electrical conductivity, mechanical strength, and flexibility [7]. Composites that include graphene are being developed for flexible electronics, while polymers infused with CNTs enhance mechanical properties and conductivity, making them ideal for wearable and stretchable smart devices.

Metallic nanomaterials

Metal nanoparticles such as silver, gold, and copper are utilized for their remarkable electrical and thermal conductivities. Silver nanoparticles are particularly valuable in creating conductive inks for printed electronics, while copper nanoparticles present a more affordable option. Gold nanoparticles are also being investigated for their potential in biosensing applications due to their compatibility with biological systems [8].

Polymeric nanocomposites

Nanocomposites are formed by embedding nanomaterials into polymeric matrices, resulting in materials with superior mechanical strength, flexibility, and thermal stability. These composites are crucial for applications demanding lightweight, durable, and multifunctional devices, such as smart wearables and energy storage technologies [9,10].

Ceramic nanomaterials

Nanoceramics like zirconia and alumina offer high thermal

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stability, chemical resistance, and mechanical hardness. These materials are used in applications that involve high temperatures and biomedical fields, such as 3D-printed bone implants and dental prosthetics [11].

The combined use of these nanomaterials with advanced 3D printing methods facilitates the creation of bespoke, high-performance smart devices, setting the stage for future advancements across various sectors.

Innovative Applications in Smart Devices

The integration of nanomaterials with 3D printing has ushered in a new era of cutting-edge smart devices. By utilizing the distinctive features of nanomaterials, such as a large surface area, high conductivity, and enhanced mechanical strength, 3D-printed gadgets are evolving to become more intelligent, efficient, and customizable [12]. Here are several noteworthy innovative uses:

Wearable electronics

Devices that use nanomaterials and are 3D-printed are spearheading advancements in personalized health monitoring. These wearable devices, featuring sensors crafted from conductive nanomaterials such as graphene or carbon nanotubes, can monitor vital signs, sense environmental shifts, and wirelessly relay data [13]. Their adaptable and stretchable nature makes them ideal for prolonged, continuous wear.

High-performance sensors

The 3D printing of nanomaterials has facilitated the development of highly sensitive sensors applicable in environmental surveillance, chemical identification, and biomedical analysis. Sensors constructed from metallic nanoparticles like silver or gold provide exceptional precision and quick response times, making them well-suited for detecting minute quantities of gases or biological indicators [14].

Energy storage and harvesting devices

Batteries and supercapacitors enhanced with nanomaterials through 3D printing exhibit increased energy density, quicker charge-discharge cycles, and extended longevity. Moreover, nanostructured materials, such as 3D-printed graphene, can be utilized in energy harvesting devices like solar panels and piezoelectric systems, paving the way for self-sustaining smart technologies [15].

Biomedical devices

In the field of biomedicine, devices based on 3D-printed nanomaterials, including implants and prosthetics, provide enhanced biocompatibility and functionality. Additionally, drug delivery systems developed with nanomaterials allow for controlled and localized release of medications, thereby improving treatment effectiveness while minimizing adverse effects.

These advancements illustrate how the combination of nanomaterials and 3D printing is revolutionizing the technology behind smart devices, propelling progress in healthcare, environmental monitoring, and energy efficiency. As research progresses, we can anticipate the emergence of even more advanced and multifunctional devices in the near future.

Challenges and Future Directions

Despite the encouraging potential of 3D-printed nanomaterials for applications in smart devices, several obstacles still exist. A significant challenge is the scalability of the printing methods, as existing technologies find it difficult to generate large quantities of high-quality, uniform nanomaterial structures [16]. Moreover, when compared to conventional manufacturing methods, the mechanical properties and compatibility of 3D-printed nanomaterials often do not meet expectations. Problems such as limited resolution, material strength, and conductivity in printed nanocomposites need to be resolved. Looking forward, upcoming innovations may prioritize the development of hybrid materials that integrate various nanomaterials for improved characteristics, as well as enhancing multi-material 3D printing techniques to create more intricate and functional devices. Additionally, research aimed at optimizing printing processes for quicker, more cost-effective production will be crucial for the widespread acceptance of these technologies in future smart devices.

Conclusions

The incorporation of 3D-printed nanomaterials has shown significant promise in transforming the creation of advanced smart devices. By merging the adaptability of 3D printing with the distinct characteristics of nanomaterials, a diverse range of applications has been developed, including wearable technology, sensors, energy storage solutions, and biomedical implants. The capacity to design and produce tailored devices at the micro and nanoscale, featuring improved mechanical, electrical, and chemical properties, paves the way for groundbreaking solutions in healthcare, electronics, and environmental assessment.

However, obstacles like scalability, material compatibility, and the need for precise control over the printing process pose major challenges to the widespread use of 3D-printed nanomaterials. As research advances in the discovery of new materials and hybrid methods, upcoming innovations are anticipated to enhance the quality, performance, and functionality of smart devices.

In the years ahead, the synergy between nanotechnology, 3D printing, and smart device engineering is expected to herald a new period of customized, high-efficiency devices that can respond to individual user preferences and surrounding conditions. Ongoing investigation and refinement of 3D-printed nanomaterials will not only propel the future of smart devices but will also broaden their capability to tackle urgent global issues related to health, sustainability, and connectivity.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

1. Hales S, Tokita E, Neupane R, Ghosh U, Elder B, Wirthlin D, et al. 3D printed nanomaterial-based electronic, biomedical, and bioelectronic devices. Nanotechnol. 2020;31(17):172001. https://doi.org/10.1088/1361-6528/ab5f29
2. Elder B, Neupane R, Tokita E, Ghosh U, Hales S, Kong YL.

https://doi.org/10.61577/jnd.2024.100005

Nanomaterial patterning in 3D printing. Adv Mater. 2020;32(17): 1907142. https://doi.org/10.1002/adma.201907142
3. Herbert R, Lim HR, Park S, Kim JH, Yeo WH. Recent advances in printing technologies of nanomaterials for implantable wireless systems in health monitoring and diagnosis. Adv Healthc Maters. 2021;10(17):2100158. https://doi.org/10.1002/adhm.202100158
4. Zhang H, He R, Niu Y, Han F, Li J, Zhang X, et al. Graphene-enabled wearable sensors for healthcare monitoring. Biosens Bioelectron. 2022;197:113777. https://doi.org/10.1016/j.bios.2021.113777
5. Yao S, Swetha P, Zhu Y. Nanomaterial-enabled wearable sensors for healthcare. Adv Healthc Maters. 2018;7(1):1700889. https://doi.org/10.1002/adhm.201700889
6. Farahani RD, Dubé M, Therriault D. Three-dimensional printing of multifunctional nanocomposites: manufacturing techniques and applications. Adv Mater. 2016;28(28):5794-821. https://doi.org/10.1002/adma.201506215
7. Das CM, Kang L, Ouyang Q, Yong KT. Advanced low-dimensional carbon materials for flexible devices. InfoMat. 2020;2(4):698-714. https://doi.org/10.1002/inf2.12073
8. Zhang J, Ahmadi M, Fargas G, Perinka N, Reguera J, Lanceros-Méndez S, et al. Silver nanoparticles for conductive inks: From synthesis and ink formulation to their use in printing technologies. Metals. 2022;12(2):234. https://doi.org/10.3390/met12020234
9. Shen X, Zheng Q, Kim JK. Rational design of two-dimensional nanofillers for polymer nanocomposites toward multifunctional applications. Prog Mater Sci. 2021;115:100708. https://doi.org/10.1016/j.pmatsci.2020.100708
10. Tripathy DB, Gupta A. Nanocomposites as sustainable smart materials: A review. J Reinf Plast Compos. 2024:07316844241233162. https://doi.org/10.1177/07316844241233162
11. Lin H, Yin C, Mo A. Zirconia based dental biomaterials: structure, mechanical properties, biocompatibility, surface modification, and applications as implant. Front Dent Med. 2021;2:689198. https://doi.org/10.3389/fdmed.2021.689198
12. Kamyshny A, Magdassi S. Conductive nanomaterials for 2D and 3D printed flexible electronics. Chem Soc Rev. 2019;48(6):1712-1740. https://doi.org/10.1039/c8cs00738a
13. Shar A, Glass P, Park SH, Joung D. 3D Printable One-Part Carbon Nanotube-Elastomer Ink for Health Monitoring Applications. Adv Funct Mater. 2023;33(5):2211079. https://doi.org/10.1002/adfm.202211079
14. Jambhulkar S, Xu W, Franklin R, Ravichandran D, Zhu Y, Song K. Integrating 3D printing and self-assembly for layered polymer/nanoparticle microstructures as high-performance sensors. J. Mater Chem C. 2020;8(28):9495-9501. https://doi.org/10.1039/d0tc02660c
15. Foster CW, Down MP, Zhang Y, Ji X, Rowley-Neale SJ, Smith GC, et al. 3D printed graphene based energy storage devices. Sci Rep. 2017;7(1):42233. https://doi.org/10.1038/srep42233
16. Zavanelli N, Kim J, Yeo WH. Recent advances in high-throughput nanomaterial manufacturing for hybrid flexible bioelectronics. Mater. 2021;14(11):2973. https://doi.org/10.3390/ma14112973

https://doi.org/10.61577/jnd.2024.100005