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Advancement in Biodegradable Equipment for Flexible and Sustainable Electronics

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Abstract

Biodegradable electronics are a quickly developing area focused on reducing the environmental impact of traditional electronic waste by using materials that can break down naturally after use. These devices use eco-friendly polymers, nanocomposites, and bio-based materials that maintain electrical function temporarily before safely decomposing. Recent developments show the potential of plant-based polymers, conductive biodegradable composites, and transient materials that support flexible and wearable applications without causing long-term harm to the environment. These materials have led to the creation of soft sensors, implantable medical tools, and short-term monitoring systems that do not require surgical removal or waste processing. This approach improves both environmental sustainability and user safety. Moreover, nanofibrous structures, electrospun composites, and biodegradable conductive polymers like polypyrrole and polythiophene have improved the mechanical strength and electrical conductivity of temporary electronic systems. However, significant challenges still exist. These include achieving consistent degradation rates, maintaining performance stability during use, and developing effective encapsulation methods that protect devices while allowing for controlled breakdown later. There are ongoing environmental concerns about the potential release of microplastics, acidic byproducts, or harmful residues during the breakdown of materials. This underscores the need for thorough lifecycle assessments of biodegradable materials. Additionally, high production costs and limited scalability compared to traditional electronics hinder widespread adoption. This indicates a need for better green manufacturing methods and more cost-efficient production techniques. Despite these obstacles, the field continues to expand as innovations in green processing, bioresorbable batteries, and self-healing conductors broaden the options for sustainable device design. Biodegradable electronics have great potential for future uses in healthcare, environmental monitoring, smart wearables, and disposable sensing platforms. Ultimately, they can help create a more environmentally responsible technology landscape.

Keywords: Biodegradable electronics, medical devices, environment, transient electronics, conductive polymers, flexible devices, sustainable materials

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INTRODUCTION

The rising issue of e-waste has pushed research toward greener options, so scientists are now building devices that break down naturally [1]. Instead of piling up trash, these gadgets rely on substances that dissolve safely over time, thereby cutting harm to nature. Biodegradable gadgets matter more now because they can work inside the body, stick to the skin for sensation, or track air and water quality [1–10]. These tools mix natural plastics with tiny, advanced materials, using fresh methods to build bendable technology that breaks down safely.

Even though it is hopeful, big hurdles still exist when lining up daily use, breakdown speed, and large-scale production. This review looks at recent progress in the area while wondering where biodegradable electronic devices might subsequently [11–19].

MATERIALS FOR BIODEGRADABLE ELECTRONICS

Polymers and Nanocomposites

Some studies have examined degradable plastics such as PLA, PGA, and PCL, which can be converted into thin films or tiny fibers for use in electronics. Instead of lasting forever, Tan et al. (2016) [1] pointed out how such materials should operate temporarily and then dissolve safely. Similarly, Li et al. [2] explored blends that completely break down, mixing plant-based plastics with graphene and electrically active polymers so that they keep working well when needed.

Nanofibrous and Composite Materials

In some situations, biodegradable plastics on their own are not strong enough or do not conduct well for electronic applications. Therefore, scientists have attempted to mix tiny fibers or blended substances. Tiny fiber-filled polymers can boost the toughness and bendability of eco-friendly materials. They work especially well when both stretchiness and toughn e s s are required in gadgets worn on the body. Nanofibers usually come from a method called electrospinning, which helps form thin, linked strands that are useful in gadgets to boost durability. Najafabadi and team in 2017 [7] tested polymer-based nanofiber mats for bendable stretchable electronics. Such materials work well when making gears that twist, extend, or fit oddly shaped surfaces, which is crucial for wearable detectors or medical tools.

Making biodegradable plastics work better involves mixing them with materials such as metals, carbon tubes, or graphene, which boosts their ability to carry electricity without losing their decay feature [2]. Li et al. pointed out how merging electric-friendly polymers with plant-based fibers, such as cellulose, helps make green gadgets more efficient [3]. These mixtures break down on schedule, so they fit well in batteries, detectors, and short-term tech gear.

Conductive Materials

Conductivity still causes significant problems with eco-friendly electronics. Kenry and Liu examined break-downable conductive plastics that can carry electricity yet dissolve safely in nature [16]. These materials, such as PPy or polythiophene, were tweaked so that they could break down easily without losing their power transfer skills. Therefore, they now work well in health monitoring and medical tools. The growth of materials that can repair themselves and bend easily is a significant step forward. Because they investigated eco-friendly conductors that fix cracks on their own, Jang's team found that they kept their full function after breaking [17]. Because this holds well under stress, they work well for bendy gadgets you wear. As soon as they are useful, they break down naturally, so they last long but do not stick around forever.

Bioderived Polymers

Uva et al. (2022) took a closer look at plant-based, biodegradable plastic materials such as cellulose, silk protein, and chitin, which show real potential for short-life electronics [8]. Coming straight from nature, these substances undergo treatments that boost how well they work in throwaway gadgets. Because they rot away naturally, leaving behind no harmful waste, they fit well with eco-safe uses [8].

ENVIRONMENTAL IMPACT

Although biodegradable electronics are designed to degrade naturally and reduce electronic waste (e-waste), there are still questions regarding the long-term environmental impact of these materials, particularly after degradation.

Biodegradation in Different Environments

The breakdown of eco-friendly technology relies heavily on where it ends [8]. While some stuff vanishes quickly in compost plants, it might just sit around unchanged in dirt or lakes. Take PLA: how quickly it fades depends on heat, moisture, and tiny living organisms; if it is cold or dry, things slow way down [1]. We are still figuring out exactly how most green plastics decompose and what happens to nature once they start falling apart. In addition, even though biodegradable substances eventually break down into safe substances, they might still leave tiny plastic bits or harmful leftovers along the way [9]. This is especially the case with biodegradable plastics—when they are not made correctly, they can split into small particles that stick around in nature. According to Uva et al. (2022) and Bonné et al. (2022), checking how these materials affect the environment throughout their entire lifespan is key, so their breakdown does not end up hurting wildlife or people [8, 9].

Toxicity and Residual Byproducts

The decay of some natural materials might leave leftovers that could cause harm without proper handling. Biodegradable plastics can emit acidic substances or toxins while breaking down, depending on how they fall apart [9]. What matters is making sure what is left after electronics break down will not hurt nature or living things [9]. Obtaining this right determines whether technology works.

ADVANCES IN DEVICE DESIGN AND FABRICATION

The creation of eco-friendly gadgets requires close attention to materials, how well they work, and how they break down safely in nature. Getting them to run smoothly when used—and then vanish on schedule afterward—is no small task.

Encapsulation and Protection

One major issue in eco-friendly electronics is the protection of sensitive parts. Ko's team tested fresh ways to properly cover up bendable, breakable gadgets [6]. Instead of just shielding them, they picked stuff that guards delicate bits from harm caused by outside forces, yet breaks apart when it should. Good wrapping methods matter a lot, so gadgets work right and fall apart only once they have done their jobs.

Biodegradable Conductive Materials

Polymers play a significant role in breakable gadgets because they can be turned into soft, bendy layers that fit well inside the technology gear. Some eco-friendly plastics that have been tested for short-lived circuits include Polylactic Acid (PLA), Polycaprolactone (PCL), Polyhydroxyalkanoates (PHA), and Polyvinyl Alcohol (PVA). People like these materials, besides breaking down naturally, they are tough enough to use and come from plants or bacteria, so they do not drain fossil supplies like regular plastic does [1, 3]. Polylactic acid (PLA) is a common biodegradable plastic made from cornstarch or sugarcane. It breaks down in compost piles as well as in nature, so it can work for throwaway gadgets [3]. In addition, PCL melts easily and bends without breaking, which means that it fits well in flexible electronic parts requiring give and bounce [1]. In addition to lab-made break-downable plastics, plant-based plastics have gained more attention. Take cellulose–It is everywhere, safe to handle, breaks down naturally, so it could work well in green tech gadgets. Work by folks such as Uva et al. in 2022 investigated stuff made from wood pulp for short-lived circuits, showing promise for throwaway electronics that do not harm the planet [8]. Chitosan is derived from shellfish skeletons, and scientists like Li's group have found it useful because it comes from nature, vanishes over time, and plays a role in living tissue [2].

Processing Techniques

Green ways to make gadgets, such as skipping solvents or using less heat, are key when building materials that break down naturally. Li et al. (2020) showed that these eco-friendly steps do not just cut pollution during manufacturing; they also help parts fall apart easily after their jobs are completed [3].

APPLICATIONS OF BIODEGRADABLE ELECTRONICS

Biodegradable electronics hold promises for a range of applications, particularly in medical devices, environmental monitoring, and wearable electronics.

Medical Devices

Biodegradable electronics are mainly helpful in medical applications, where devices such as implants, sensors, and drug liberation systems can be planned to function for a short-term before being absorbed by the body. Yedrissov et al. (2022) proposed a new compound substance for biodegradable electronics used in medical plans, highlighting the need for materials that can melt safely in the human body without causing adverse effects [4]. Such devices could eliminate the need for surgical elimination, thereby offering an important improvement in healthcare expertise.

Environmental Monitoring and Wearables

The push for eco-friendly wearables is sparking curiosity about disposable sensors, warming elements, and gadgets that fit naturally on the skin. Instead of lasting forever, Basarir's team introduced flexible pressure detectors that dissolve once done [18]. Because they vanish over time, there is no clean-up hassle. These innovations might change how we see smart clothing, swapping out rigid circuits for greener options. New ideas in eco-friendly technology might change how we track nature. Nyamayaro's team in 2020 tested tiny diodes built from plant crystals mixed with seaweed gel, intended for short-term sensor jobs [14]. They monitor temperature or moisture levels, yet when done, break down naturally instead of polluting the soil. No trash was left behind after they faded away.

CHALLENGES AND FUTURE DIRECTIONS

Although biodegradable electronics offer significant advantages, several challenges remain in realizing their full potential.

Stability and Performance

One big issue with eco-friendly electronics is keeping them working well when they are needed. To prevent breakdowns too soon, decay requires tight control; therefore, functions do not stop early. Research by Bonné et al. in 2022 shows that using special bacteria inside green materials might help track or speed up rotting, but only when wanted [9].

Biodegradation Rate Control

Achieving a steady breakdown helps gadgets work properly without harming nature. Although some tests checked how stuff like silk or plant plastic breaks down, we still need clear rules to measure eco-friendly technological decay [8]. As every material acts differently, scientists must dig deeper into real-world conditions instead of lab-only results [9].

Cost and Scalability

The cost of creating biodegradable electronics remains high, especially for regular gadgets. Scaling up how we make these materials, along with producing parts cheaply in large amounts, still requires work [3]. Examining eco-friendly methods and better manufacturing might lower expenses, opening the door for wider adoption [5].

Mechanical Properties and Flexibility

Many gadgets, especially those you wear, require parts that bend but still hold up. Instead of simply using breakable plastics, such as PLA or PCL, scientists look at tiny fiber networks made by spinning methods. These ultrathin fibers provide better stretches and toughness for eco-friendly circuits [7]. However, such fine structures may weaken over time when used daily. In wearable devices, gadgets usually face constant bending, and they are stretched or twisted. These materials must keep working even when bent, with no cracks or loss of electric performance. According to Tan et al. (2016), mixing break-downable materials with stretchiness and toughness matters a lot if we want wider use, particularly in flexible technology, you can wear [1].

Electrical Conductivity

Electrical conductivity is a different issue. Getting enough electrical flow without losing the ability to break down naturally. Metals, such as gold or copper, also things, such as silicon, are great at moving electricity, yet they do not decompose, piling up as electronic trash. Materials such as polypyrrole or polythiophene can carry current, although they are usually not as strong in performance when stacked against standard options. Kenry and Liu (2018) investigated biodegradable conductive plastics, pointing out that they work okay in some cases but do not carry current like metal or silicon do [16]. Because of this gap, they are not suitable for high-speed technology such as combs, gears, or power tools. In addition, heat and moisture tend to mess with the performance of these plastics over time (Figure 1).

CHEMICAL DEGRADATION EQUATIONS

1. Magnesium-based wire or battery anode [12]
   $Mg+2H_2O \rightarrow Mg(OH)_2+H_2\uparrow$
2. Zinc conductor degradation [12]
   $Zn+2H_2O \rightarrow Zn(OH)_2+H_2$
3. PLA/PCL polymer substrate degradation [1, 3]
   Hydrolysis of ester bonds-
   $R\text{-}COO\text{-}R'+H_2O \rightarrow R\text{-}COOH+R'\text{-}OH$
4. Self-healing method of PVA hydrogel [17]
   $PVA\text{-}OH+B(OH)_3 \rightleftharpoons PVA\text{-}O\text{-}B(O)_2\text{-}O\text{-}PVA$
5. Termination of cellulose-based hydrogels [8]
   $(C_6H_{10}O_5)n+nH_2O \rightarrow nC_6H_{12}O_6$

CONCLUSION

Biodegradable gadgets are growing rapidly, offering a greener path for technological staff. Owing to new materials such as breakable plastics, tiny fibers, and conductive compounds, progress has been made. Still, there is work to do—getting them to rot at the right pace while keeping power steady is difficult. Making it larger, factory style? That's another hurdle. As studies continue, these eco-friendly gadgets might help cut down old device trash, especially in health tools you wear. Thanks to the emergence of new ideas, technology that breaks down naturally could change how we use electronics, fitting better with a greener tomorrow.

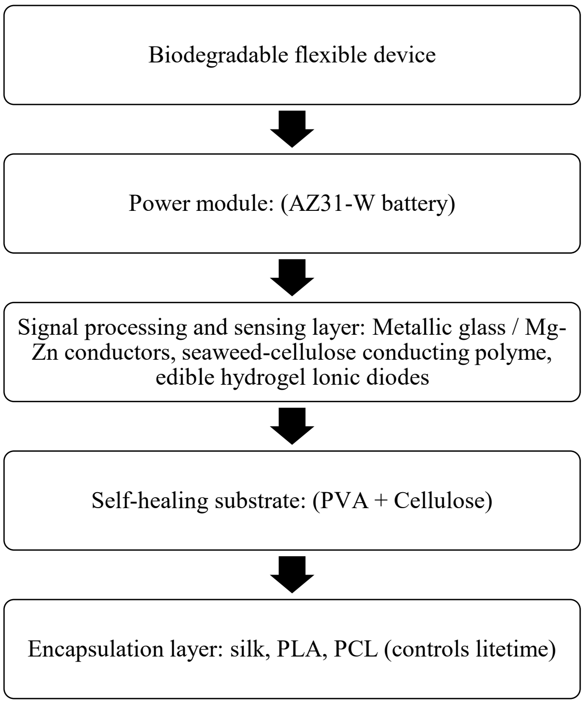

Figure 1. System block diagram.

REFERENCES

1. Tan MJ, Owh C, Chee PL, Kyaw AKK, Kai D, Loh XJ. Biodegradable electronics: cornerstone for sustainable electronics and transient applications. J Mater Chem C. 2016;4:5531–5558. doi:10.1039/C6TC00678G.
2. Li R, Wang L, Kong D, Yin L. Recent progress on biodegradable materials and transient electronics. Bioact Mater. 2018;3:322–333. doi:10.1016/j.bioactmat.2017.12.001.
3. Li W, Liu Q, Zhang Y, Li C, He Z, Choy WCH, et al. Biodegradable materials and green processing for green electronics. Adv Mater. 2020;32:e2001591. doi:10.1002/adma.202001591.
4. Yedrissov A, Khrustalev D, Alekseev A, Khrustaleva A, Vetrova A. New composite material for biodegradable electronics. Mater Today Proc. 2022;49:2443–2448. doi:10.1016/j.matpr.2020.11.053.
5. Han WB, Lee JH, Shin JW, Hwang SW. Advanced materials and systems for biodegradable, transient electronics. Adv Mater. 2020;32:e2002211. doi:10.1002/adma.202002211.
6. Ko GJ, Kang H, Han WB, Dutta A, Shin JW, Jang TM, et al. Materials and designs for extremely efficient encapsulation of soft, biodegradable electronics. Adv Funct Mater. 2024;34:2403427. doi:10.1002/adfm.202403427.
7. Najafabadi AH, Tamayol A, Annabi N, Ochoa M, Mostafalu P, Akbari M, et al. Biodegradable nanofibrous polymeric substrates for generating elastic and flexible electronics. Adv Mater. 2014;26:5823–5830. doi:10.1002/adma.201401537.
8. Uva A, Lin A, Babi J, Tran H. Bioderived and degradable polymers for transient electronics. J Chem Technol Biotechnol. 2022;97:801–809. doi:10.1002/jctb.6790.
9. Bonné R, Wouters K, Lustermans JJM, Manca JV. Biomaterials and electroactive bacteria for biodegradable electronics. Front Microbiol. 2022;13:906363. doi:10.3389/fmicb.2022.906363.
10. Morfa AJ, Rödlmeier T, Jürgensen N, Stolz S, Hernandez-Sosa G. Comparison of biodegradable substrates for printed organic electronic devices. Cellulose. 2016;23:3809–3817. doi:10.1007/s10570-016-1049-0.
11. Liu K, Tran H, Feig VR, Bao Z. Biodegradable and stretchable polymeric materials for transient electronic devices. MRS Bull. 2020;45:96–102. doi:10.1557/mrs.2020.24.
12. Bae JY, Gwak EJ, Hwang GS, Hwang HW, Lee DJ, Lee JS, et al. Biodegradable metallic glass for stretchable transient electronics. Adv Sci. 2021;8:2004029. doi:10.1002/advs.202004029.
13. Nyamayaro K, Keyvani P, D'Acierno F, Poisson J, Hudson ZM, Michal CA, et al. Toward biodegradable electronics: ionic diodes based on a cellulose nanocrystal–agarose hydrogel. ACS Appl Mater Interfaces. 2020;12:52182–52191. doi:10.1021/acsami.0c15601.
14. Ko GJ, Jang TM, Shin D, Kang H, Yang SM, Han S, et al. Long-lasting, flexible and fully bioresorbable AZ31-tungsten batteries for transient, biodegradable electronics. J Mater Chem A. 2024;12:32712–32720. doi:10.1039/D4TA06222A.
15. Li H, Gao F, Wang P, Yin L, Ji N, Zhang L, et al. Biodegradable flexible electronic device with controlled drug release for cancer treatment. ACS Appl Mater Interfaces. 2021;13:21067–21075. doi:10.1021/acsami.1c04653.
16. Kenry, Liu B. Recent advances in biodegradable conducting polymers and their biomedical applications. Biomacromolecules. 2018;19:1783–1803. doi:10.1021/acs.biomac.8b00275.
17. Jang TM, Han WB, Han S, Dutta A, Lim JH, Kim T, et al. Stretchable and biodegradable self-healing conductors for multifunctional electronics. Sci Adv. 2024;10:eadp9818. doi:10.1126/sciadv.adp9818.
18. Basarir F, Haj YA, Zou F, De S, Nguyen A, Frey A, et al. Edible and biodegradable wearable capacitive pressure sensors: a paradigm shift toward sustainable electronics with biobased materials. Adv Funct Mater. 2024;34:2403268. doi:10.1002/adfm.202403268.
19. Teo MY, Lim K, Aw KC, Kee S, Stringer J. Towards biodegradable conducting polymers by incorporating seaweed cellulose for decomposable wearable heaters. RSC Adv. 2023;13:26267–26274. doi:10.1039/D3RA04927B.

