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APPLICATIONS OF BATTERIES USED IN THE TEXTILE FIELD

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Abstract: *Batteries are important in our daily lives and are used in various devices, from mobile phones and laptops to electric cars and solar energy storage systems. However, there are other areas where batteries can be used to improve the functionality and performance of products, such as the textile industry. Batteries are critical components in power systems for electronic devices. An emerging application of batteries is in the textile field, where they are used to power electronic devices integrated into fabrics. Smart textile technology has become an important research area, with applications in health, sports and fashion. This technology can be used to monitor the vital parameters of the body, to help improve sports performance and to create clothes with special features, such as heating or cooling. However, for these fabrics to work, a the energy source to power the incorporated electronic devices. This is a critical problem because conventional batteries are bulky and rigid, making integrating them into fabrics challenging. Flexible batteries are a potential solution to this problem. They are made using flexible materials such as polymers or metals. Flexible batteries can be integrated directly into fabrics, making using them in smart textile applications possible.*

Key words: *batteries, smart textiles, functionality, performance, mobility*

1. INTRODUCTION

The development of flexible electronics such as textile heating systems and the desire of users to wear them anywhere has led to intense research on integrating batteries into clothing, miniaturization, performance and ensuring optimal energy consumption to keep the body warm.
Another application of batteries in the textile field is incorporating electronic devices into fabrics. Fabrics that can store and release electrical energy can be used to charge portable electronic devices such as mobile phones, tablets or electronic systems integrated into bracelets for monitoring.

As all electronic devices require energy, developing flexible, lightweight batteries is a significant design challenge for smart textiles [1].

Power generation can be achieved by piezoelectric elements that harvest energy from movement or photovoltaic elements. Human interfaces to active systems can be roughly grouped into input devices and annunciation or display devices. Input devices can include capacitive portions that function like buttons or shape-sensitive fabrics that can sense movement, bending, pressure, and stretching or compression. Advertising and display devices may include material speakers, electroluminescent wires, or wires that are processed to contain arrays of organic light-emitting diodes (OLEDs) [1].

2. BATTERIES USED IN THE TEXTILE FIELD

Batteries can be integrated into wearable e-textile applications, but it is necessary for the electronic device to be energy efficient to limit the battery's size. An efficient, light and flexible source is needed to power all the components in a smart textile.

Ideally, such a source will be a fiber that can be naturally integrated into smart textiles during weaving [2].

Flexible, fiber-shaped batteries embedded in textiles are convenient for charging gadgets like fitness bands, smart watches, and phones. Researchers have made fiber-shaped batteries by twisting or winding different battery materials or coating them in layers on polymer fibers or metal wires. The realization of fiber batteries with high functionality is well reduced to the quality of the material coatings [3].

Recent years have shown rapid progress in research into surface-applied or garment-embedded flexible electronics for various applications, including healthcare and other sensing functionalities, with many of these devices based on conventional electronic circuit elements and substrates, such as printed circuit boards and, therefore, rigid and inflexible, which limits their practical applications on a large scale and also ease of carrying.

These new types of smart textiles provide a means of embedding electronic functions and conductive threads into the fabric to make them smart wearables for various applications. However, like other electronic devices, they need a power source, one of the biggest challenges limiting their commercialization. Integrating the power source into textiles has its own consequences for the wearer's overall well-being, replaceability and flexibility.

Usually, in conventional approaches, rigid and bulky batteries or capacitors are used as energy storage devices for e-textiles. Studies suggest that all battery components must be made of flexible substrate materials to replace these rigid devices or batteries with flexible ones. In addition to flexibility, lightness and comfort, when these textile electronic devices are used explicitly close to the human body, the materials used to build the electronic components, such as the battery, should be non-toxic and environmentally friendly [4].

Power generation can also be achieved by one or a combination of energy capture systems, such as:

- piezoelectric or triboelectric elements, which store energy from the movement of the human body;
- radio frequency (RF) energy harvesting, which requires an RF source to be close to the carrier;
- solar energy harvesters, where energy can be collected at certain times of the day or combining these harvesting methods with one of the energy storage devices.

Compared to other methods, harvesting mechanical energy using piezoelectric or triboelectric nanogenerators is the most widespread harvesting method available in all living environments, including our bodies. The energy collected by the energy capture methods mentioned above can be converted into useful electrical energy. However, they present several disadvantages, such as more space, similar to traditional energy storage devices (figure 1), which contain a container, cathode, separator, anode, electrodes, electrolyte and collector, also needing a component rigid electronics that limit the flexibility of the smart fabrics they power. Energy collection and storage systems based on textiles could be the best alternative for powering small e-textile devices if they ensure the required energy performance (figure 2).

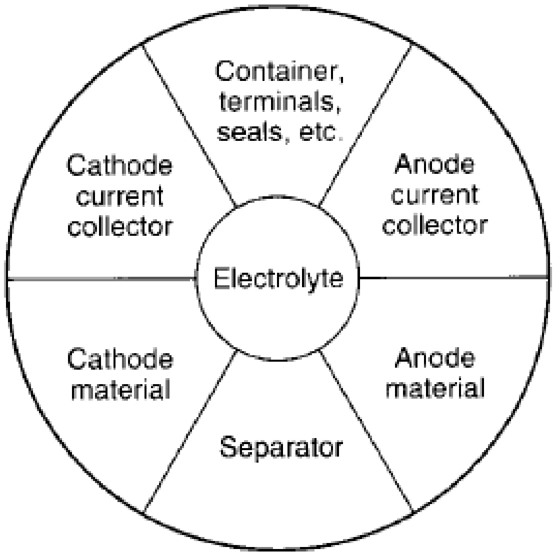

Fig. 1. Cell battery components [5]

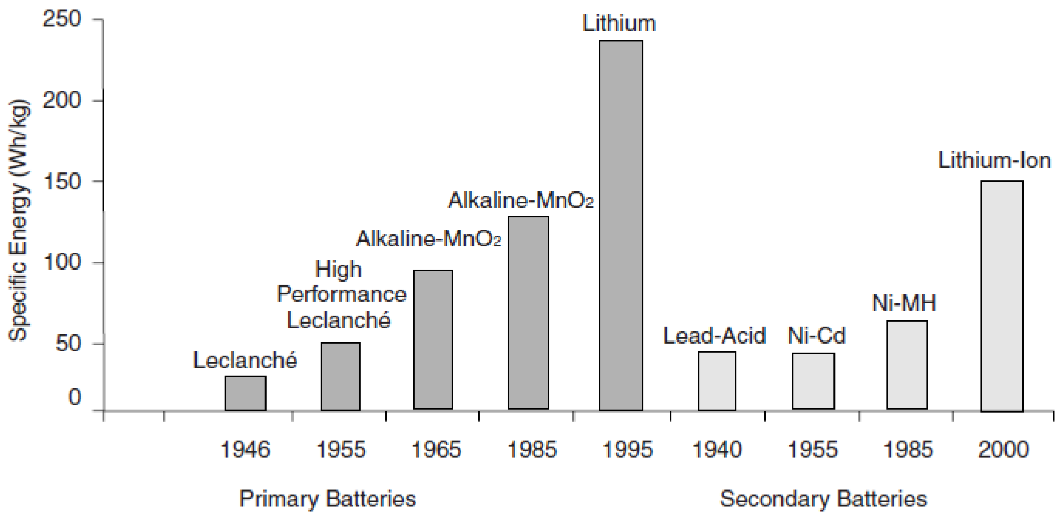

Fig. 2. Batteries performance for portable applications [5]

3. TYPES OF BATTERIES

3.1. Printed batteries

Printed batteries are of increasing interest to research and industry because they are ultra-thin, lightweight and have a low environmental impact. The individual components of the printed battery, including an electrolyte or separator, electrodes and current collector, must be manufactured using printing technologies.

Electrode design and battery architecture are crucial to producing an efficient battery. The two most common printed battery designs are stack or sandwich with coplanar or parallel architectures. The stacking architecture consists of two electrodes, a current collector for each electrode and an electrolyte separator, all printed on flexible support materials of specific thickness. Lithium-ion and alkaline zinc-dioxide manganese batteries are the most popular batteries made by 3D printing technologies [6]. Stack architecture is frequently used for lithium-ion batteries because it leads to low internal impedance due to the short distance the ions travel between the two electrodes.

On the other hand, the coplanar architecture, which consists of the two electrodes placed in a side-by-side arrangement, as opposed to the sandwich type, is frequently applied in the design of expandable batteries. The overall flexibility of the battery is based on the mechanical properties of the separate components [4].

3.2. Li-ion batteries

Due to their design and composition, lithium-ion batteries enable the production of reliable, low-cost, high-capacity energy sources. For Li-ion batteries to be suitable for smart textiles, ideally, such batteries should be flexible and not contain any liquid electrolyte [3].

Lithium-ion batteries are the latest in rechargeable battery technology and their market potential is proliferating with increased levels of investment in various value chains worldwide. Lithium rigid batteries produced in metal foil materials are powerful and greatly influence battery technology for various applications due to their high energy density and longer discharge life. In the last ten years, there have been achievements for the development of flexible lithium-ion batteries; however, due to the limited capacity and high mass per unit volume of the electrode materials, increasing the energy density while maintaining the flexibility, weight, and charge/discharge cycle stability of the battery is still a challenge [4].

3.3. Alkaline batteries

To generate electricity, alkaline batteries are based on chemical reactions (1) between zinc (anode) and magnesium dioxide (cathode) and the alkaline electrolyte potassium hydroxide (KOH). These batteries develop a specific energy of 145 Wh/kg and a specific density of 400 Wh/L [5].

$$Zn + 2MnO_2 \rightarrow ZnO + Mn_2O_3 \quad \textbf{(1)}$$

The basic electrolytes for these chemical reactions are potassium hydroxide (KOH) or sodium hydroxide (NaOH).

The most commonly used alkaline batteries applied for smart textiles and wearables consist of zinc-manganese dioxide (Zn-MnO2) batteries and silver-zinc oxide (Ag2O-Zn) monovalent batteries [4].

3.4. Water-based Li-ion batteries

One way to mitigate the air and water sensitivity and flammability of LIBs is to replace flammable organic electrolyte solutions with aqueous electrolytes.

Transition metal oxides, such as those in conventional LIBs have been used as active electrode materials. Lithium intercalation was the charge transfer mechanism to both the positive and negative electrodes so that the battery would perform the same way as conventional LIBs [7].

3.5. Metal-air batteries

Metal-air batteries are those in which oxygen from the ambient air is reduced, with the help of a catalyst, at the cathode during discharge [8].

Concomitant, the metal anode is oxidized, and the reactions of both electrodes can be reversible, forming a rechargeable battery. Rechargeable metal-air batteries can be composed of many different metal-electrolyte-catalyst compositions, aqueous or non-aqueous, and are seen as a promising technology due to their high theoretical energy density.

Metal-air batteries can be an attractive option to textile batteries because they are meant to be exposed to air and are insensitive to moisture.

Non-rechargeable zinc-air batteries have been widely commercialized for medical, military and industrial applications. They are considered the ideal power source for hearing aids due to their high volumetric energy, low cost and environmental friendliness.

Aluminium-air batteries produce electricity through the chemical reaction of oxygen in the air with aluminium and have been intensively researched due to their high theoretical capacity and energy. They were mainly considered for military and niche applications. However, there have been limited applications due to technical challenges, including anode corrosion, inability to reach theoretical voltages, water consumption during discharge, and lack of rechargeability [5].

4. CONCLUSIONS

Wearable batteries have essential requirements, such as flexibility, lightness and convenience. However, powering them remains challenging despite advances in the development of wearable and textile electronic devices. Actually, the power supply devices are typically built from rigid and bulky materials and often require more space than those they power.

Therefore, ensuring the supply of electrical energy and the efficiency of electrical energy consumption for flexible textile electronic devices is essential.

In conclusion, batteries and accumulators have significant potential in the textile field. From improving the performance of textile materials to developing smart fabrics that can monitor human health and provide electricity, textile batteries represent a new frontier of innovation in textiles and electronics.

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REFERENCES

[1] M. Stoppa and A. Chiolerio, *"Wearable electronics and smart textiles: A critical review. sensors"*, 14(7), 2014, pp.11957-11992.

[2] H. Qu, J.P. Bourgeois, J. Rolland, J., A. Vlad, J.F. Gohy and M. Skorobogatiy, *"Flexible fiber batteries for applications in smart textiles"*, MRS Online Proceedings Library (OPL), 1489, 2013, pp.mrsf12-1489.

[3] P. Prachi, *"High-performance textile batteries made by the spool. Robust coating method produces lithium-fiber batteries that can recharge a cell phone"*, C&EN, 99(33), 2021.

[4] A.E. Ali, V. Jeoti and G.M. Stojanović, *"Fabric based printed-distributed battery for wearable e-textiles: a review"*, Science and Technology of Advanced Materials, 22(1), 2021, pp.772-793.

[5] D. Linden, "*Handbook of batteries. In Fuel and energy abstracts*", 4(36), 1995, p. 265.

[6] K. Sztymela, M. Bienia, F. Rossignol, S. Mailley, S. Ziesche, J. Varghese and M. Cerbelaud, *"Fabrication of modern lithium ion batteries by 3D inkjet printing: opportunities and challenges",* Heliyon, 2022, p.e12623.

[7] N. S. Hudak, *"Water -Based Textile Batteries"*, 2019.

[8] Y. Li and J. Lu, "*Metal–air batteries: will they be the future electrochemical energy storage device of choice?"*, ACS Energy Letters, 2(6), 2017, pp.1370-1377.