

Development of 3D Knitted Fabrics for Triboelectric Energy Generation

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I. INTRODUCTION

The demand for sustainable energy solutions has been driving the exploration of alternative energy generation technologies. Triboelectric nanogenerators (TENGs) are one such promising solution, capable of converting mechanical energy into electrical energy by exploiting [1] the triboelectric effect. TENGs offer a clean, renewable source of energy by harnessing movements, vibrations, and friction from human activity. With the increasing popularity of wearable technology, integrating energy-harvesting fabrics into clothing presents a significant opportunity to create self-powered systems. [2]

This study focuses on developing 3D knitted fabrics specifically designed for triboelectric energy generation. Traditional fabrics are limited in their surface area and mechanical properties, leading to suboptimal energy harvesting efficiency. By utilizing advanced knitting techniques to create three-dimensional structures, the potential for maximizing the triboelectric effect is enhanced. The primary goal of this project is to develop durable, flexible, and efficient 3D knitted fabrics that can power low-energy electronics, such as sensors, through human movement.[3]

II. LITERATURE REVIEW

Triboelectric nanogenerators have gained considerable attention due to their ability to harvest energy from various mechanical activities, including human motion, wind, and waves.[4] The concept relies on triboelectrification, where friction between two materials causes a transfer of electrons, creating an electrical charge. The wearable sector, especially, stands to benefit from this technology, as fitness trackers,

health monitors, and other wearable devices can operate continuously without the need for external power sources like batteries.[5]

Previous studies have explored the use of TENGs in different configurations, including single-electrode, vertical contact-separation, and lateral sliding modes.[6] Textile-based TENGs are an emerging focus area due to their potential for integration into wearable products. Woven and non-woven fabrics have been investigated for their triboelectric properties, but 3D knitted fabrics are underexplored despite their advantages in flexibility, durability, and customization.[1]

III. MATERIALS AND METHODS

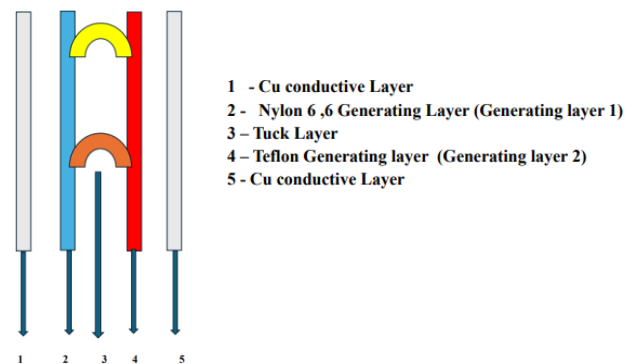


Fig 1. structure of the 3D fabric

To address the limitations of existing fabrics, this research involved designing and fabricating multi-layered 3D knitted fabrics using a combination of conductive and triboelectric materials. Copper (Cu) conductive yarns were used for the inner layers to form the conductive network, while Nylon 6,6 and Teflon were selected as the triboelectric materials for their electron-donating and electron-accepting properties, respectively.[7]

The fabric was produced using a Shima-Seiki flatbed knitting machine, with five layers: two Cu conductive layers, two triboelectric layers (Nylon 6,6 and Teflon), and a tuck layer to maintain structure and flexibility. The design aimed to maximize the surface area of contact between the triboelectric layers while ensuring the fabric retained the flexibility required for wearable applications. Various knitting structures were trialed to identify the configuration with the best triboelectric performance.[8]

The knitted fabric was tested using an oscilloscope and a digital micrometer to measure its electrical output when subjected to sliding movements. Additionally, key wearable properties, including GSM (grams per square meter), breathability, and washability, were evaluated to ensure the fabric's suitability for real-world applications.

IV. RESULTS AND DISCUSSION

The final 3D knitted fabric demonstrated significant improvements in triboelectric energy generation compared to traditional flat fabrics. When tested under controlled sliding conditions, the fabric produced an electrical output ranging from 1 to 3 volts. Although this output is lower than that of conventional energy sources, it is sufficient for powering low-energy sensors and other small electronics in wearable applications.

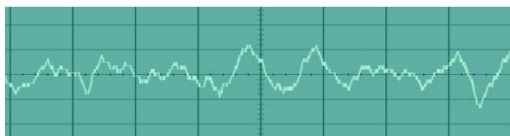


Fig 2. current output With higher sliding speeds



Fig 3. current output With medium sliding speeds

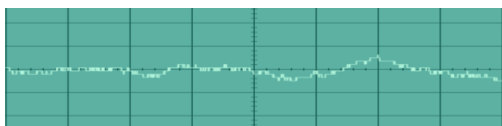


Fig 4. current output With low sliding speeds

One of the primary challenges encountered was maintaining the balance between energy generation efficiency and fabric weight. The GSM of the fabric was initially high, at 538.46 GSM, which affected its suitability for wearables. However, through adjustments in yarn selection and fabric structure, the final version achieved a reduced GSM of 350, making it more

suitable for wearable technology. The use of Cu conductive yarns with a resistance of $2 \Omega \text{ m}^{-1}$ helped maintain a good level of conductivity while keeping the fabric's weight manageable.

Breathability tests conducted using the Atlas air permeability tester indicated good air permeability, with a value of $120 \text{ cm}^3/\text{cm}^2/\text{s}$. This ensures that the fabric can be worn comfortably over long periods without causing overheating or discomfort. Additionally, the fabric underwent three wash cycles simulating real-world conditions, and it maintained its structural integrity and electrical properties, confirming its durability and washability.

Despite these positive outcomes, there remain areas for improvement. The electrical output of the fabric, while measurable, is not yet at a level that can fully replace external power sources in most wearable applications. Future research should focus on optimizing the fabric structure and material composition to enhance energy generation efficiency. Exploring the use of higher-performance conductive materials, such as silver-coated yarns, could further improve the fabric's performance.

V. CONCLUSION

This study successfully developed a 3D knitted fabric with triboelectric energy generation capabilities, marking a significant step toward self-powered wearable technology. The optimized fabric configuration, featuring Cu conductive yarns and triboelectric layers of Nylon 6,6 and Teflon, demonstrated measurable electrical output and excellent wearable properties, including breathability and washability. However, further research is needed to improve the energy generation efficiency to make the fabric more viable for broader applications.

By addressing current limitations in fabric weight and energy output, this research lays the groundwork for future advancements in triboelectric textiles. The integration of such fabrics into wearable devices could lead to new opportunities in healthcare, personal electronics, and even defense, providing a sustainable, self-powered solution to meet the growing demand for wearable technology.

VI. FUTURE WORK

Future research will focus on optimizing the triboelectric properties of the fabric through material innovation and structural improvements. The possibility of incorporating new triboelectric materials with enhanced electron-donating or electron-accepting characteristics should be explored.

Additionally, reducing fabric weight further without compromising performance is critical for achieving widespread adoption in wearable technology. Finally, testing the fabric under real-world conditions and scaling up the manufacturing process will be necessary to bring this innovative fabric to market.

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