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A Triboelectric Nanogenerator Based on Bamboo Leaf for Biomechanical Energy Harvesting and Self-Powered Touch Sensing

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Abstract: Recently, natural material-based triboelectric nanogenerators (TENGs) have increasingly attracted attention in academic circles. In this work, we have developed an innovative triboelectric nanogenerator (BL-TENG) utilizing bamboo leaves to capture biomechanical energy. Bamboo leaf, as a natural plant material, possesses a diverse array of applications due to its remarkable durability, which surpasses that of many other types of trees. Furthermore, bamboo leaf has the advantages of low cost, widely distributed, non-toxic and environmentally protected. The output power of the BL-TENG (size: 5 cm × 5 cm) is able to generate approximately 409.6 μ W and the internal resistance of the BL-TENG is 40 M Ω . Furthermore, the BL-TENG can realize an open-circuit voltage (Voc) of 191 V and a short-circuit current (Isc) of 5 μ A, respectively. The biomechanical energy harvesting effect of the BL-TENG device means that it can drive 18 commercial light-emitting diodes (LEDs) through the full-wave bridge rectifier. Furthermore, the BL-TENG can also serve as a self-powered touch sensor to reflect hand touch states. This study proposed a novel plant-based TENG device that can enhance the development of green TENG devices and self-powered sensing systems.



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Keywords: triboelectric nanogenerator (TENG); bamboo leaf; sensor

1. Introduction

Due to the rise in pollution and the accelerating depletion of conventional fossil fuels, the need for renewable energy has become increasingly important. [1–3]. Green energy, such as wind energy, solar energy, and ocean wave energy, has great application prospects and potential and does not produce additional emissions [4–6]. Further, with the rapid development of the Internet of Things (IoT), distributed sensing technology is becoming an important means of adaptive detection of a complex adaptive environment, and wireless sensor network technology promotes the development of the IoT [7,8]. Thus, distributed generation based on clean and renewable energy is an indispensable and effective complement to centralized power generation and of great strategic significance to alleviating the increasingly serious energy and environmental crises [9,10]. Related power generation technologies, including electromagnetic power generation, photovoltaic power generation, and thermoelectric power generation, have become a research hotspot in current scientific research. However, the energy acquisition device based on these power generation technologies has the disadvantages of high cost, large floor area, and being harmful to the environment. This further limits its application in distributed sensor networks [11–13]. Often, chemical batteries can provide electrical energy for these electronic devices, but this

causes problems in terms of the need for repeated replacement of batteries, leading to high maintenance costs. Therefore, developing new energy harvesting technology is beneficial to promoting the distributed sensor network based on the IoT.

In 2012, for the first time, Professor Wang reported a novel triboelectric nanogenerator (TENG) technology which can realize low-frequency mechanical energy harvesting and convert it into electrical energy [14–21]. Compared with traditional electromagnetic power generation technology, TENG technology has a lower-cost preparation process and a wider range of application scenarios. It can collect many types of mechanical energy, such as water drop energy, breeze, ocean wave energy, tidal energy, human motion energy, etc. [22–26]. Especially for mechanical energy generated by low-frequency and low-amplitude motion, the TENG device can achieve a better energy conversion effect, which has unique advantages. It is worth mentioning that the raw materials for preparing TENG devices come from a wide range of sources, which brings convenience to the production of large-scale power generation devices [27,28]. TENG devices can be prepared from metals, organic polymers, natural biomaterials, and plant materials [29–33]. Furthermore, TENG devices exhibit marvelous physical properties and have potential applications including as a self-powered sensor system, high-voltage power source, and environmental monitoring system. This new power generation technology will play the role of green energy while protecting the environment. Searching novel triboelectric materials without additional processing has become a new research idea for pushing forward the development of TENGs. From previous work [34–38], plant materials such as lotus leaves, petals, and tea leaves can be utilized in TENG device fabrication. TENG devices based on plant materials have the advantages of being environmentally friendly, low carbon, low pollution, and low cost. Interestingly, the wide range of plant materials provides a low-cost advantage for the preparation of TENG. Moreover, there are many micro and nanostructures on the surface of natural plants, which is an important characteristic to improve the performance of TENG devices. Thus, developing novel plant-based triboelectric material is necessary and meaningful for designing large-scale distributed TENG energy supply networks. Furthermore, the micro–nano triboelectric surface endows TENG with unique applications in touch sensors. By constructing a self-powered triboelectric touch sensing model and promoting the development of animal networking technology, it will contribute to the incubation of new technologies. It is worth noting that there are many micro-structures on the surface of plants, which bring high sensitivity to touch sensors. Through further device structure design, plant-based triboelectric sensors can play a role in daily life.

In this work, we have developed an innovative triboelectric nanogenerator (BL-TENG) utilizing bamboo leaves to capture biomechanical energy. As a natural plant material, bamboo leaves have a wide range of uses, and their excellent wear resistance is stronger than that of other trees. Furthermore, bamboo leaf has the advantages of being low cost, widely distributed, non-toxic and environmentally protected. It is very suitable for the role of triboelectric materials. In this work, we developed the triboelectric property of bamboo leaf through a series of experiments. The polytetrafluoroethylene (PTFE) film and bamboo leaf layer constitute the triboelectric layers, and the conductive copper serves as the conductive electrode. Furthermore, the BL-TENG can realize an open-circuit voltage (V_{oc}) of 191 V and short-circuit current (I_{sc}) of 5 μA , respectively. The biomechanical energy harvesting effect of the BL-TENG device means that it can drive 18 commercial light-emitting diodes (LEDs) through the full-wave bridge rectifier. Furthermore, the BL-TENG device can also serve as a self-powered touch sensor to reflect hand touch states.

2. Materials and Methods

As the triboelectric layer, bamboo leaf needs to have high frictional strength. Generally, the leaf needs to grow for more than a year to serve as the triboelectric layer. The bamboo leaf needs to be cleaned with deionized water to remove surface dirt that may affect output performance. In this research, the bamboo leaf and PTFE film are harmoniously paired as a triboelectric combination, while conductive copper tape assumes a dual role as both the

electrode for the BL-TENG and the carrier for the triboelectric materials. Figure 1a offers a comprehensive insight into the fabrication process for the top section of the BL-TENG. Initially, cardboard is meticulously cut into two substrates, each measuring $5\text{ cm} \times 5\text{ cm}$. Subsequently, conductive copper foil tape is meticulously applied to the surface of one of the substrates, ensuring that the adhesive side faces upward, as elucidated in Figure 1(a1,a2). Following this step, the PTFE film is meticulously affixed to the adhesive surface of the conductive copper foil tape, resulting in the formation of the top section of the BL-TENG device (Figure 1(a3)). The corresponding photograph of the PTFE layer is thoughtfully presented in Figure 1f.

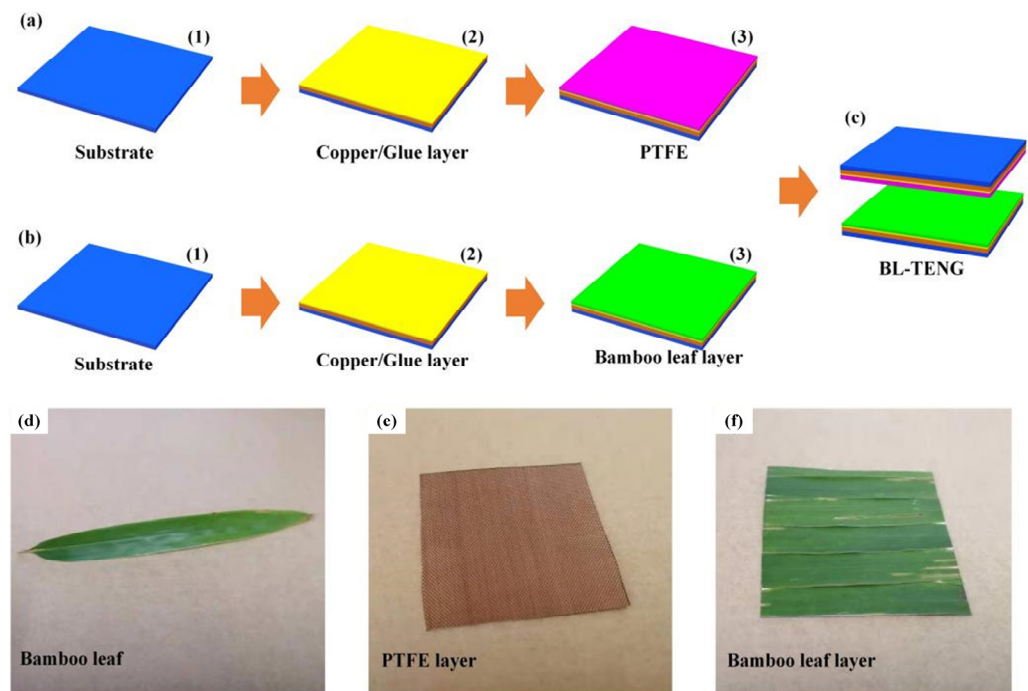


Figure 1. The fabrication process of (a) the top part and (b) the bottom part of the BL-TENG. (c) The overview diagram of the BL-TENG. Physical photograph of (d) bamboo leaf, (e) PTFE layer, and (f) bamboo leaf layer.

This comprehensive description delves deeply into the intricacies of the fabrication process, underscoring the paramount importance of precision and alignment in the creation of an efficient and functional triboelectric nanogenerator utilizing bamboo leaves and PTFE film. Additionally, an analogous procedure is replicated for the counterpart substrate. Conductive copper foil tape is meticulously attached to its surface, ensuring the adhesive side faces upward, as depicted in Figure 1(b1,b2). Subsequently, bamboo leaves are meticulously applied to the adhesive surface, constituting the foundational component of the BL-TENG (Figure 1(b3)). The photographic representation of the bamboo leaf layer is vividly illustrated in Figure 1f. Ultimately, the two discrete sections seamlessly amalgamate to conclude the assembly of the BL-TENG, as portrayed in Figure 1c. The photographic depiction of the integrated bamboo leaf element is prominently featured in Figure 1d. This exhaustive elucidation of the fabrication process underscores the systematic assembly of the BL-TENG components, accentuating the meticulous steps involved in the creation of a proficient and operational triboelectric nanogenerator utilizing bamboo leaves and PTFE film.

In this work, the mechanical vibrating system, including signal generator, power amplifier, and exciter, was used to provide the driving force for BL-TENG. A hot press machine is used for the preparation of bamboo leaf film. In addition, the V_{oc} , I_{sc} , and Q_{sc} of BL-TENG was measured by using the electrometer (Keithley 6517, Keithley Instruments Inc, Cleveland, Ohio, USA). We provided the scanning electron microscope (SEM) image of

the bamboo leaf surface in Figure S1 in the Supplementary Materials. Obviously, the rough surface texture of bamboo leaf can enhance the contact efficiency of triboelectric surfaces, thereby achieving the influence of improving BL-TENG's electrical output. Furthermore, the good flexibility of bamboo leaf can also give devices the advantage of bending resistance. The easy degradation of plant fibers can play a role in protecting the environment and reducing pollution.

3. Results

The electrical output of a triboelectric nanogenerator (TENG) hinges on the divergence in electron gain and loss capabilities between the two triboelectric materials involved. Essentially, the higher the disparity in their capacity to gain or lose electrons, the greater the electrical performance yielded by TENG devices. Consequently, the triboelectric properties of the materials play a pivotal role in influencing the output of TENG devices. In order to comprehensively investigate and comprehend the triboelectric properties of bamboo leaves, a series of comparative experiments was conducted. This systematic exploration aims to shed light on the nuanced interplay of electron transfer dynamics between bamboo leaves and other triboelectric materials, providing valuable insights for the advancement of TENG technology.

In our experimental design, we compared the electrical output of four TENGs (size: 1 cm × 1 cm) with different pairs, including PTFE@BL, Kapton@BL, PET@BL, and nylon@BL to determine the triboelectric sequence of BL. According to results in Figure 2a, the maximum I_{sc} peak value of four TENGs based on PTFE@BL, Kapton@BL, PET@BL, and nylon@BL can be 2.61 μA , 1.79 μA , 1.16 μA , and $-0.55 \mu\text{A}$, respectively. Meanwhile, the maximum Q_{sc} peak value of four TENGs based on PTFE@BL, Kapton@BL, PET@BL, and nylon@BL can be 23 nC, 20 nC, 15 nC, and -9 nC , as illustrated in Figure 2b. Hence, the ability of triboelectric sequences to obtain electrons increases from weak to strong is PTFE, Kapton, PET, BL, and nylon. Furthermore, the special triboelectric characteristics also endow BL-TENG with potential as a touch sensor, which can be utilized in wearable electronic devices and other fields in the future.

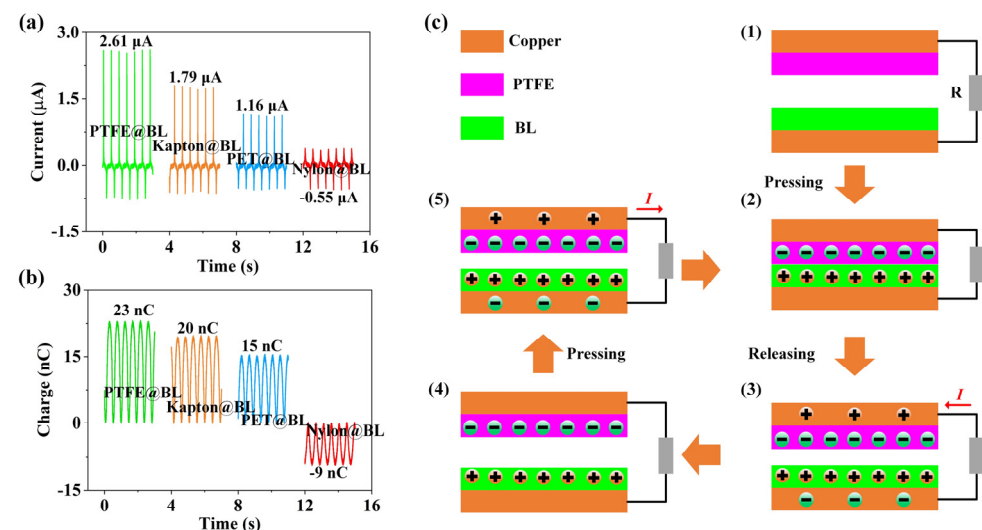


Figure 2. (a,b) The comparative experimental results of bamboo leaf's triboelectric properties. (c(1)–c(5)) The working mechanism of BL–TENG.

Bamboo leaves, positioned uniquely in this context, demonstrate distinctive characteristics that contribute to their role in enhancing the overall efficiency of TENGs. In this study, the BL-TENG device is based on the vertical contact-separation model, and the operational mechanism of the BL-TENG is elucidated in Figure 2(c1–c5). Figure 2(c1) portrays the initial state of the BL-TENG device, in which no electrons are generated on the surfaces of the PTFE film and bamboo leaf. When external force is applied, causing the surfaces of the

PTFE film and bamboo leaf to come into contact, electrons migrate on these surfaces. As illustrated in Figure 2(c2), the separation between the two triboelectric surfaces results in a negative charge on the PTFE film surface and a positive charge on the bamboo leaf surface. Upon parting the two surfaces, as depicted in Figure 2(c3), a positive charge emerges on the top electrode, accompanied by a negative charge on the bottom electrode, giving rise to the generation of a circuit-induced current signal. Gradually increasing the separation distance leads to the positive and negative charges within the electrode saturating, and ultimately reaching the zenith of the output current; this is convincingly illustrated in Figure 2(c4). Conversely, when the two triboelectric material surfaces draw closer to each other, a reverse current signal manifests within the circuit, as explicitly presented in Figure 2(c5). This in-depth exploration into the operational mechanism sheds light on the dynamic processes intricately involved in the BL-TENG's functionality, underscoring its inherent capability to produce electrical output through meticulously controlled contact-separation actions.

In the examination of TENG device output performance, it is imperative to evaluate various parameters, including maximum output power, V_{oc} , I_{sc} , transferred charge, and more. This study employed a mechanical vibration exciter as the driving force for the BL-TENG device, with the S-TENG device measuring approximately $5\text{ cm} \times 5\text{ cm}$. The experimental setup involved securing the top part of the BL-TENG to the motion section of the mechanical vibration exciter, while the bottom part was firmly affixed to the substrate. To systematically assess the electrical output characteristics of the BL-TENG, different resistance loads were methodically connected to the device. Subsequent measurements of the electrical output, encompassing output voltage and current, were conducted and are visually represented in Figure 3a. This comprehensive experimental approach ensures a detailed analysis of the device's response to varying load conditions. Furthermore, the utilization of a mechanical vibration exciter introduces controlled external force, allowing for a precise examination of the BL-TENG's performance under specific driving conditions. The systematic connection of resistance loads adds granularity to the assessment, enabling insights into how the device responds to different electrical loads. This detailed investigation serves to unravel the nuanced dynamics of the BL-TENG device's electrical output, contributing to a thorough understanding of its capabilities and potential applications. Therefore, the experimental setup, driven by a mechanical vibration exciter and incorporating diverse resistance loads, provides a robust platform for the comprehensive evaluation of the BL-TENG device's electrical performance. The results obtained under varying load conditions contribute valuable data for optimizing the device's functionality and exploring its potential applications in energy harvesting.

The results obtained from our experiments underscore the dynamic relationship between the load resistance and the electrical output of the BL-TENG. Notably, as the load resistance increases from $1\text{ M}\Omega$ to $1\text{ G}\Omega$, a discernable trend emerges: the output voltage of the BL-TENG exhibits an increment, while the output current experiences a decrease. This intricate interplay is graphically represented in Figure 3a, providing a visual representation of how load resistance influences the electrical performance of the BL-TENG. In addition to load resistance considerations, the maximum output power (P) of the BL-TENG was meticulously calculated using the relationship $P = UI$, where U represents the output voltage and I denotes the output current. The results, showcased in Figure 3b, reveal that the BL-TENG attains a peak output power of $409.6\text{ }\mu\text{W}$ under an internal resistance of $40\text{ M}\Omega$. Considering the size of the device is $5\text{ cm} \times 5\text{ cm}$, the maximum power density of BL-TENG can reach $16.4\text{ }\mu\text{W}/\text{cm}^2$. This insight into the device's power generation capabilities highlights its efficiency under specific electrical conditions. Furthermore, the V_{oc} and I_{sc} of the BL-TENG devices were determined to delve deeper into their electrical characteristics. Figure 3c,d illustrate that the BL-TENG can achieve a V_{oc} of 191 V and I_{sc} of $5\text{ }\mu\text{A}$, respectively. These parameters provide valuable metrics for understanding the device's performance under different operational scenarios.

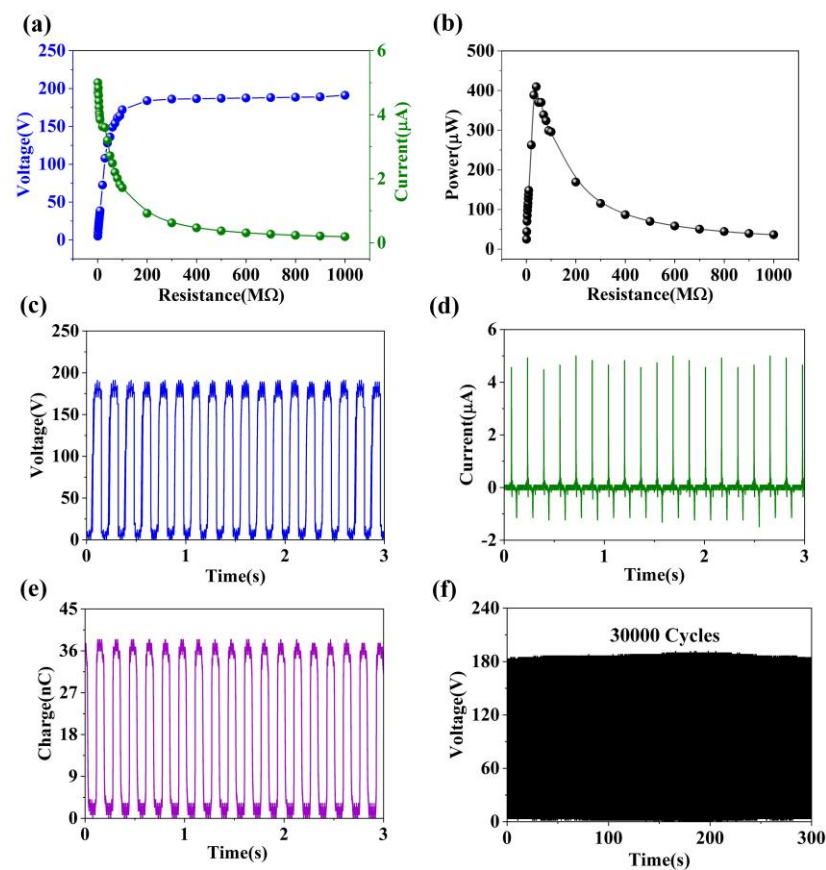


Figure 3. (a) The electrical output of BL-TENG. (b) The calculated values of BL–TENG output power. The (c) Voc, (d) Isc, and (e) charge transfer of the BL-TENG device. (f) The reliability analysis of BL-TENG under 30,000 operation cycles.

Equally crucial is the assessment of the charge transfer capabilities of the BL-TENG, represented by the transferred charge. Figure 3e showcases that the BL-TENG is capable of transferring 38.4 nC of charge, emphasizing its efficacy in generating and transferring electrical charge during operation. Importantly, the endurance and stability of the BL-TENG were scrutinized through continuous operation. The device exhibited remarkable stability after enduring 30,000 cycles at a working frequency of 10 Hz. This endurance test not only validates the robustness of the BL-TENG, but also underscores its reliability over extended operational cycles. Thus, this comprehensive evaluation provides multifaceted insights into the robust performance and reliability of the BL-TENG device. The capacity to generate substantial electrical output under varying conditions, coupled with its stability over prolonged operational cycles, positions the BL-TENG as a promising candidate for diverse practical applications in energy harvesting and related fields.

As illustrated in Figure 4a, the Isc of the S-TENG exhibits a gradual increase from 1.83 μA to 5 μA as the working frequency escalates from 2 Hz to 6 Hz; this is attributed to the heightened charge transfer rate. Intriguingly, for the BL-TENG, as depicted in Figure 4b,c, there is a conspicuous absence of significant variation in Voc and transferred charge as the working frequency spans from 2 Hz to 6 Hz. This implies that the BL-TENG showcases a robust capacity to generate substantial electrical output even under low-frequency working conditions. Furthermore, a detailed examination of the charging efficiency of the BL-TENG with a full-wave bridge rectifier is meticulously presented in Figure 4d. The charging curves under different working frequencies and diverse capacitors are comprehensively expounded upon in Figure 4e,f, offering profound insights into the distinctive behavior of the BL-TENG across varying operational parameters. These nuanced observations

contribute significantly to a more comprehensive understanding of the device's intricate performance characteristics and reinforce its potential applications across diverse scenarios.

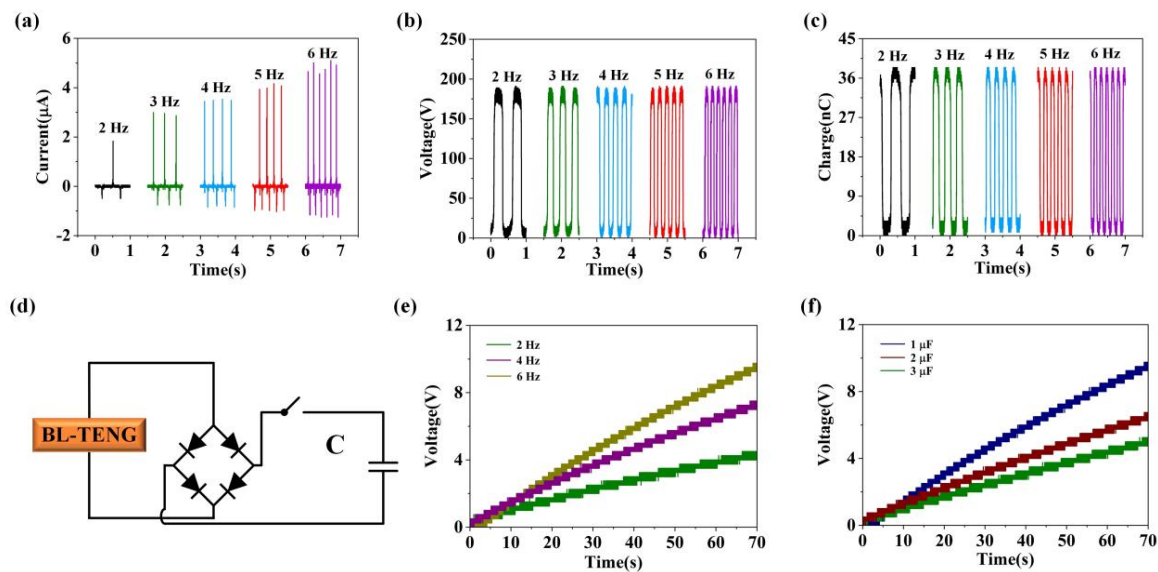


Figure 4. The (a) I_{sc} , (b) V_{oc} , and (c) transfer charge of BL-TENG under working frequencies. (d) Diagram illustrating the power management circuit utilizing the BL-TENG for charging a capacitor. (e) Charging profiles and (f) charging characteristics at 6 Hz.

Additionally, a thorough examination of the charging efficiency of the BL-TENG was meticulously conducted, employing a full-wave bridge rectifier, as visually represented in Figure 4d. The charging curves, which are intricately documented under various working frequencies and with an array of capacitors, are systematically elucidated. Delving deeper into the exploration, Figure 4e meticulously outlines the charging profiles of the BL-TENG with a $1\ \mu\text{F}$ capacitor under diverse operational frequencies (2 Hz, 4 Hz, and 6 Hz). Expanding the scope of the investigation, Figure 4f intricately details the charging characteristics of the BL-TENG with capacitors of different values ($1\ \mu\text{F}$, $2\ \mu\text{F}$, and $3\ \mu\text{F}$) while maintaining a consistent working frequency of 6 Hz.

These comprehensive and intricate findings provide valuable insights into the distinctive characteristics and robust performance of the BL-TENG across a wide spectrum of frequencies and capacitor configurations. The results not only underscore the potential versatility of the BL-TENG but also emphasize its efficacy for a diverse array of practical applications. The detailed analysis of charging efficiency contributes to a deeper understanding of the device's behavior under varied operational conditions, enhancing its applicability and reliability in real-world scenarios.

Considering the inherent limitations posed by the size of bamboo leaves, we have implemented a pioneering tailoring process designed to streamline the production of devices with diverse dimensions. This meticulous approach involves the precise cutting of bamboo leaves into various sizes, followed by a strategic assembly process to facilitate the development of larger devices. As illustrated in Figure 5a, bamboo leaf layers with different sizes ($1\ \text{cm}^2$, $4\ \text{cm}^2$, $9\ \text{cm}^2$, $16\ \text{cm}^2$, and $25\ \text{cm}^2$) have been meticulously crafted. This tailored process not only showcases the adaptability but also contributes to the versatility of the fabrication method, enabling the production of devices with varied sizes to suit specific requirements.

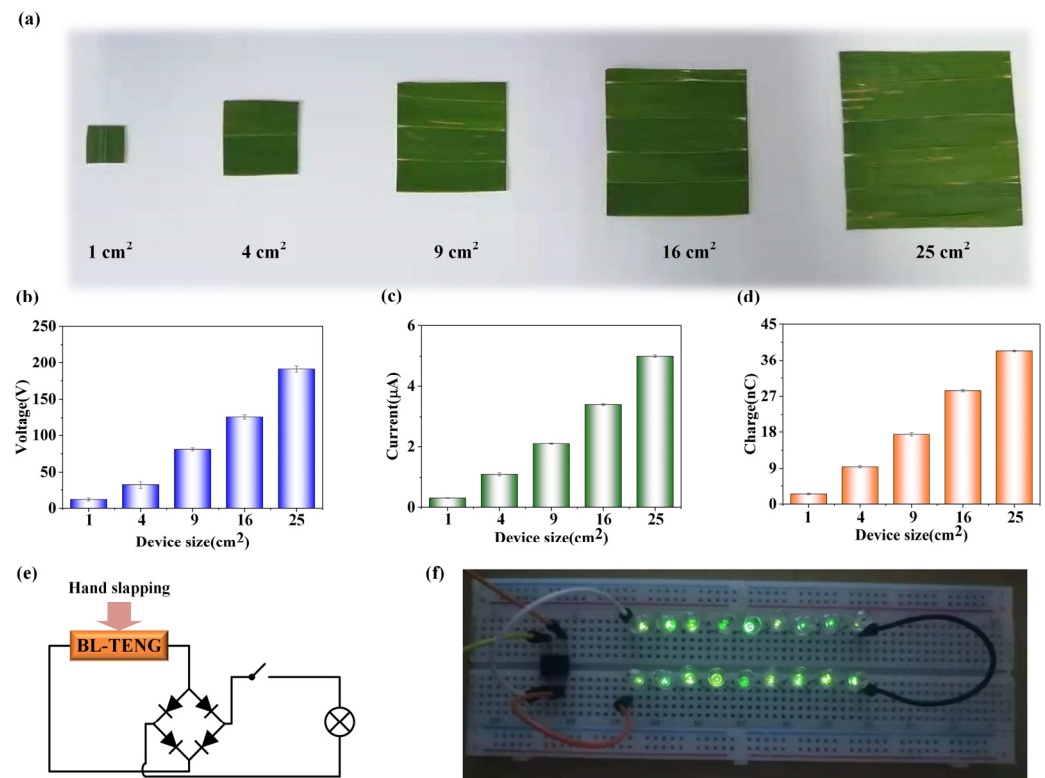


Figure 5. (a) Physical photograph of the bamboo leaf layer with different sizes (1 cm², 4 cm², 9 cm², 16 cm², and 25 cm²). The (b) Voc, (c) Isc, and (d) transfer charge of BL-TENG with different sizes. (e) Test diagram of LEDs by the BL-TENG. (f) Photograph of 18 LEDs lit by hand-tapping of the BL-TENG.

Furthermore, a comprehensive analysis of the output performance of BL-TENG devices across different sizes has been conducted. As depicted in Figure 5b, the Voc (open-circuit voltage) of the BL-TENG exhibits a significant increase, ranging from 12 V to 191 V, corresponding to the variation in device size from 1 cm² to 25 cm². Similarly, the Isc (short-circuit current) of the BL-TENG, showcased in Figure 5c,d, experiences a growth from 0.3 μA to 5 μA, accompanied by an escalation in the transferred charge from 2.5 nC to 36 nC. These observations underscore the adaptability of the BL-TENG's output performance, showcasing that the device's capabilities are not limited by the initial size of the bamboo leaf when leveraging the tailoring process for device size adjustments. This tailoring approach proves effective in enhancing the scalability and performance flexibility of the BL-TENG.

Expanding on the exploration of the biomechanical energy harvesting capabilities of the BL-TENG device (size: 4 cm × 4 cm), an insightful experiment was conducted involving the mechanical action of hand slapping. The harvested energy was skillfully harnessed to illuminate a set of 18 commercial LEDs through the incorporation of a full-wave bridge rectifier, vividly depicted in Figure 5e,f. This impactful demonstration not only showcases the immediate practicality of the BL-TENG in harnessing biomechanical energy but also emphasizes its efficiency in powering diverse applications. The ability to effectively convert mechanical energy into electrical power positions the BL-TENG as a versatile and promising solution for biomechanical energy harvesting in various scenarios. We compared the electrical output change of two TENGs (size: 5 cm × 5 cm) based on bamboo leaf and ordinary leaf after continuous operation of 50,000 cycles, under the same conditions. From the results in Figure S2a of the Supplementary Materials, the electrical output of TENG based on bamboo leaf can maintain stable output performance. However, the electrical output of TENG based on ordinary leaf will experience a 16% attenuation after continuous operation of 50,000 cycles, as shown in Figure S2b of the Supplementary Materials. The

stable output of TENG based on bamboo leaf is attributed to the high fatigue resistance of bamboo leaf compared to ordinary leaf.

In addition, we measured the long-term stability of the BL-TENG in terms of days. After four days of storage, the bamboo leaves turned yellow and dried. According to the results in Figure S3 of the Supplementary Materials, when BL-TENG is placed from the first day to the fourth day, the V_{oc} of BL-TENG increases from 25 V to 69 V. The reason for the increase in output performance is that as the storage time increases, the moisture in the bamboo leaves continuously evaporates, leading to an increase in BL-TENG output performance.

To emphasize the remarkable sensing capabilities of our innovation, we have implemented an advanced self-powered sensing system based on the BL-TENG device. The TENG device, illustrated in Figure 6a–c, seamlessly operates in a single-electrode working mode. The output voltage signal generated by the BL-TENG sensing system adeptly captures various touch states when interfaced with a matched load of 100 M Ω . A meticulous exploration, involving comprehensive measurements of the output voltage signal, was conducted under diverse touch scenarios, deliberately incorporating variations such as slow presses and releases, quick presses and slow releases, and rapid presses and releases. This detailed examination provides a thorough understanding of the BL-TENG sensing system's robust performance in discerning nuanced touch dynamics. The implementation of a matched load of 100 M Ω ensures optimal operation and sensitivity of the sensing system. The comprehensive measurements under different touch scenarios further highlight the versatility and reliability of the BL-TENG device as a self-powered touch sensor.

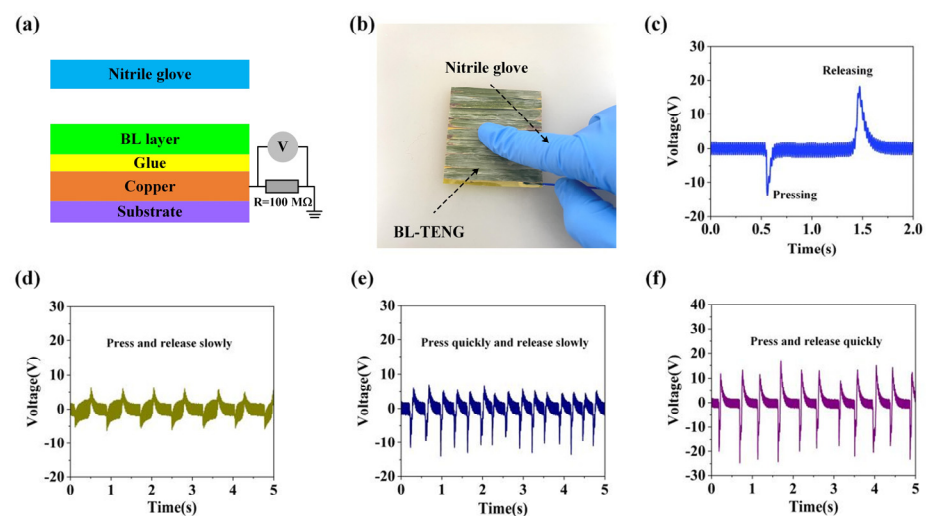


Figure 6. (a) Touch system by BL–TENG measured by using electrometer. (b) The photograph of touch system based on the BL–TENG. (c) The electrical output signal of BL–TENG under a working cycle. (d–f) The electrical output signal of BL-TENG subject to various touch statuses.

The comprehensive insights derived from the detailed findings visually presented in Figure 6d–f unequivocally underscore that the positive and negative peaks of the output signal distinctly function as reliable indicators of the speed associated with both pressing and releasing states. This captivating and sophisticated design not only enhances the reliability of touch detection but also holds substantial potential for transformative applications in touch-screen technology. The BL-TENG sensing system, owing to its inherent self-powered nature and its remarkable ability to discern nuanced touch dynamics introduces exciting and promising avenues for the augmentation of touch-sensitive interfaces. In essence, the device's unique capability to precisely reflect touch speed through distinct signal peaks further underscores its exceptional value in the progressive evolution of touch-screen technologies. This innovation represents a significant step forward in the realm of touch-sensitive interfaces, offering a self-powered solution that can effectively capture and interpret a range of touch dynamics. As touch screens continue to play a crucial role in

various technological applications, the BL-TENG sensing system stands out as a promising advancement that can contribute to the enhanced functionality and user experience of touch-sensitive devices.

It is noted that the captivating results obtained from this exploration showcase the potential applications of the BL-TENG sensing system in touch-screen technology. The self-powered nature of the system, coupled with its ability to discern intricate touch dynamics, positions it as a promising technology for enhancing touch-sensitive interfaces. The distinctive capability to reflect touch speed through distinct signal peaks further underscores its potential value in advancing touch-screen technologies.

4. Conclusions

In conclusion, our innovative triboelectric nanogenerator (TENG) harnessing the potential of bamboo leaves emerges as a cost-effective, widely available, non-toxic, and environmentally friendly solution for capturing biomechanical energy. Bamboo leaves, exhibiting favorable triboelectric properties, are well suited for their role as effective triboelectric materials. Through a systematic series of experiments, we characterized and optimized the triboelectric performance of bamboo leaves. The resulting BL-TENG device, featuring dimensions of 5 cm × 5 cm, showcases a peak output power of approximately 409.6 μ W, along with an internal resistance of 40 M Ω . Furthermore, the BL-TENG attains an impressive V_{oc} (open-circuit voltage) of 191 V and I_{sc} (short-circuit current) of 5 μ A. Demonstrating its practical utility, the BL-TENG successfully powers 18 commercial light-emitting diodes (LEDs) through a full-wave bridge rectifier, showcasing its effective biomechanical energy harvesting capabilities. Beyond energy harvesting, the BL-TENG device also proves its versatility by serving as a self-powered touch sensor, adeptly reflecting various hand touch states. This multifunctional device not only underscores the potential of bamboo leaves in energy harvesting applications but also highlights their capacity for diverse sensing functionalities.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/electronics13040766/s1>, Figure S1: The SEM image of bamboo leaf surface; Figure S2: (a,b). The reliability comparison of two TENGs based on bamboo leaf and ordinary leaf; Figure S3: The long-term stability of BL-TENGs in terms of days.

Author Contributions: Conceptualization, Z.X., Y.C. and Z.Z.; Methodology, Y.C.; Investigation, Z.X.; Writing—original draft, Z.X.; Writing—review & editing, Y.C.; Supervision, Z.Z. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: Data are contained within the article.

Conflicts of Interest: The authors declare no conflicts of interest.

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