

Cu/PTFE triboelectric nanogenerator for Morse code and array information detection

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Cu/PTFE triboelectric nanogenerator for Morse code and array information detection

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The application of triboelectric nanogenerators (TENGs) for collecting and converting waste energy into usable electrical energy has been widely reported. However, their practical application in real-time, self-powered communication systems, particularly for robust information transmission, remains underexplored. To achieve stable self-energy supply information transmission, this study presents a lightweight and flexible single-electrode TENG sensor based on a copper (Cu) foil and polytetrafluoroethylene (PTFE) composite. We systematically studied the stability of the device and found that it could maintain an output voltage of approximately 9 V after being stored at room temperature for 1 month. We also evaluated its power generation capacity, which was demonstrated by successfully lighting up to seven LEDs simultaneously. Additionally, we utilized its unique voltage signal to transmit Morse code and successfully sent the messages "SOS" and "HELLO" over a long distance. Furthermore, a 2×2 TENG array was fabricated and tested, confirming excellent channel independence with minimal crosstalk during simultaneous or selective activation. This work demonstrates that the Cu/PTFE TENG sensor is not only a stable energy harvester but also a viable platform for self-powered communication and distributed sensing and holds promise in applications integrating flexible electronics and the Internet of things.

Keywords: triboelectric nanogenerator (TENG), self-powered sensor, Morse code communication, energy harvesting, array independence

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1. Introduction

The growing demand for sustainable energy solutions and self-powered systems[1–3] has catalyzed significant advances in energy harvesting technologies.[4–6] Among these innovations, triboelectric nanogenerators[7–11] (TENGs) have emerged as a promising method due to their capacity to convert ambient mechanical energy[12] into usable electricity through the coupling of triboelectricity and electrostatic induction.[13] Since their inception, TENGs have demonstrated remarkable potential in powering wearable electronics,[14–17] environmental sensors, and Internet of things[18] (IoT) devices, owing to their flexibility, low cost and compatibility with diverse materials, which means that TENG may have unique application prospects in encrypted information transmission. Many research studies have been dedicated to integrating flexible electronic technology with Morse code transmitting equipment, which provides more possibilities for convenient and accurate transmission of Morse code. For example, researchers have employed wearable pressure sensors,[19,20] humidity sensors,[21] etc. for Morse code transmission, which greatly reduces the size of the Morse code transmitter; however, an external power source remains necessary.

This study addresses a significant gap by developing a lightweight, single-electrode TENG-based sensor composed of copper (Cu) foil and polytetrafluoroethylene (PTFE). The device exploits the inherent difference in electron affinity between human skin and PTFE to generate alternating electrical signals through contact–separation motion.[22] The Cu foil used in fabricating the TENG is inherently flexible — being widely utilized in the manufacturing of flexible electronic devices — and the PTFE film employed also exhibits excellent flexibility, resulting in superior mechanical properties for the devices. As such, it can endure diverse complex mechanical deformations while demonstrating high flexibility. Compared with the TENG materials used in Refs. [23,24], the mass per square centimeter of the material in this experiment is approximately 111 mg, which is relatively lighter. The maximum voltage generated per square centimeter by the materials in this work is approximately 6.8 V, which is slightly lower than that generated by the materials in the above references. However, the materials in this experiment are more readily available and easier to fabricate, with lower costs and reduced time consumption.

In addition to validating its stability and power output capabilities, this research demonstrates a novel application of a TENG in Morse code[23,24] communication. By encoding voltage signals as dots (·) and dashes (−), the device successfully transmits messages such as "SOS" and "HELLO", demonstrating its practicality for information transfer. Fur-

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thermore, a 2×2 TENG array[25] is investigated to highlight the system's scalability and independence, underscoring its potential for self-powered sensing[26–29] and distributed energy harvesting. Therefore, this work not only expands the functional scope of TENGs but also extends to real-time communication where sustainability and autonomy are paramount.

2. Results and discussion

2.1. The self-powered principle and structure of the TENG

A simple process was used to prepare the Cu/PTFE-based TENG. Both the Cu foil and PTFE employed in the experiment were 0.1 mm thick. Firstly, the protective paper covering the adhesive side of the Cu foil tape was removed and then the Cu foil and PTFE film were cut. They must have the same shape and a uniform size of 2.5 cm $\times$ 2.5 cm to meet the experimental requirements. Since one side of the Cu foil tape used in the experiment is strongly adhesive, the adhesive side of the Cu foil was completely bonded to the PTFE film according to the cut shape, ensuring that the surface was flat.

A metal wire was inserted into the middle layer of Cu foil and PTFE film. Finally, the layers were tightly adhered together to complete sensor preparation. Figure 1 illustrates the fundamental structure and operational mechanism of the TENG, employing a single-electrode mode. When PTFE comes into contact with human skin, electrons migrate from the skin to PTFE due to the latter's stronger electron-attracting ability. When PTFE is fully in contact with human skin (step I), an electrically balanced state ensues. Subsequently, as the skin separates from PTFE (step II), the electrostatic charge on the Cu attracts cations, causing them to accumulate at the interface between Cu and PTFE, establishing a potential difference with the ground. This results in electrons flowing from the metal wire to the ground, thereby producing a positive signal in the external circuit. When the skin and material reach their maximum separation distance (step III), a new electrostatic equilibrium is established, with no signal output. As the skin reapproaches PTFE (step IV), electrons are transferred back from the ground to the metal wire, generating a negative electrical signal. Consequently, alternating electrical signals are produced by continuous contact and separation between human skin and the material.

The method for producing a TENG is straightforward and cost-effective, paving the way for the efficient manufacturing of various flexible electronic devices in the future. The TENG is prepared by directly bonding Cu foil and modified PTFE film, and the prepared TENG can be cut into various shapes to adapt to different application scenarios. Scanning electron microscope (SEM) images reveal the cross-sectional structure of the TENG (Fig. 2(a)), while energy-dispersive x-ray (EDX) results confirm the presence of elements within the material (Fig. 2(b)), with spectral peaks corresponding to the characteristic elements of the material: carbon (C), oxygen (O) and Cu. Subsequently, a quantitative analysis of the relative proportions of these characteristic elements in the material was conducted, anticipating a high content of C and Cu and a lower content of O. The EDX spectral analysis provides a detailed distribution of elements within the material, with the spectral image representing the distribution of each element in the sample through the use of distinct colors (Fig. 2(c)). The primary components, C and O, are uniformly distributed throughout the material. Given the use of Cu foil in production, the material also contains a significant amount of elemental Cu (Figs. 2(d)–2(f)).

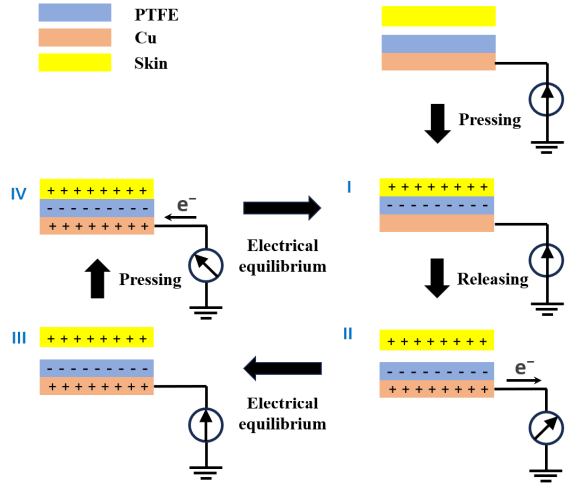


Fig. 1. Schematic diagram of the power supply for a triboelectric nanogenerator.

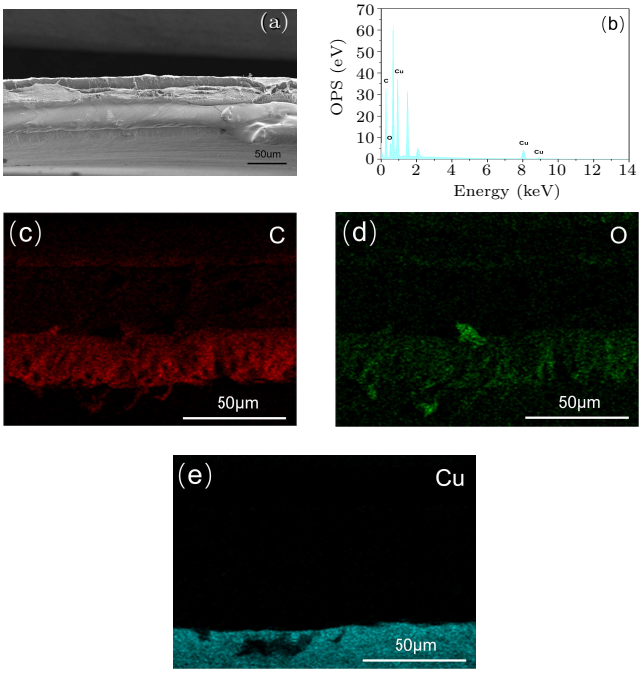
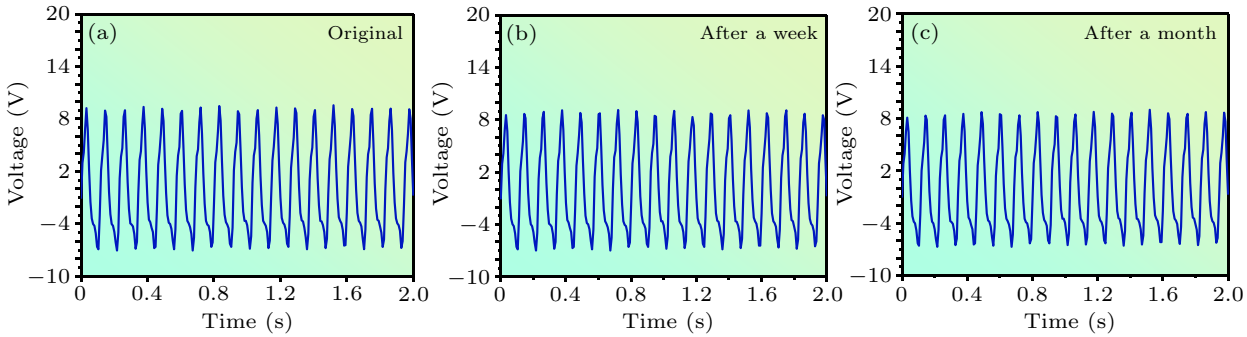


Fig. 2. Basic structure of device materials: (a) cross-sectional SEM image; (b) EDX image of the material; (c), (d), (e) corresponding EDS images.

2.2. Stability performance testing of the TENG

The TENG crafted from PTFE film and Cu foil demonstrated remarkable stability. Initially, a consistent force was applied to tap the material surface at a specified frequency, and the resulting electrical signal was recorded using an oscilloscope (Fig. 3(a)). The image revealed the generation of a well-defined periodic electrical signal with a voltage of approximately 0–9 V. After being left at room temperature for a week, the material surface was again tapped with the same force and frequency and the electrical signal was captured using an oscilloscope (Fig. 3(b)). Upon comparing the initial measurement image, it was evident that the voltage magnitude of the TENG remained almost unchanged. Subsequently, the device was placed under identical environmental conditions for 1 month, during which electrical signals were measured weekly using the same method. These measurements were then compared with the initial two sets of recorded data. A comparison between the data obtained after 1 month of placement and that after 1 week revealed a slight voltage drop of less than 1 V, indicating minimal change. The average peak voltage, voltage standard deviation and variation in the average peak voltage before and after the measurement of the electrical signals in the three graphs were calculated and compared in a table. The results further verify that the voltage variation is negligible (Fig. 3(d)). This underscores the potential of this TENG for sustained use over an extended period.



(d)

Placement time	Average value of peak voltage	Standard deviation	Average voltage variation
Initial	9.11 V	5.21 V	0 V
After a week	8.87 V	5.11 V	0.24 V
After a month	8.49 V	4.93 V	0.38 V

Fig. 3. Electrical signal images for stability testing of materials. (a) Initial measurement of electrical signal. (b) Electrical signal measured 1 week later. (c) Electrical signal measured 1 month later. (d) Statistical table for comparison of electrical signal parameters.

2.3. Power supply capability testing of the TENG

It has already been demonstrated that TENGs can produce electrical signals. However, if TENGs are to be integrated into practical everyday applications they must generate sufficient electrical energy. Therefore, the power supply capability of the TENG was verified by powering a series circuit consisting of five blue LED lights and two white LED lights (Fig. 4(a)). During the experiment, one hand held the negative terminal of the circuit, serving as the ground, while the other hand made contact with the TENG material to complete the circuit (Fig. 4(b)). In a dark environment, the surface of the TENG was tapped repeatedly to observe the illumination status of the LED lights. When an external force was applied to the material, the LED lights were illuminated (Fig. 4(c)). The brightness of the LED lights varied depending on the force applied. Even after multiple taps, the LED lights remained

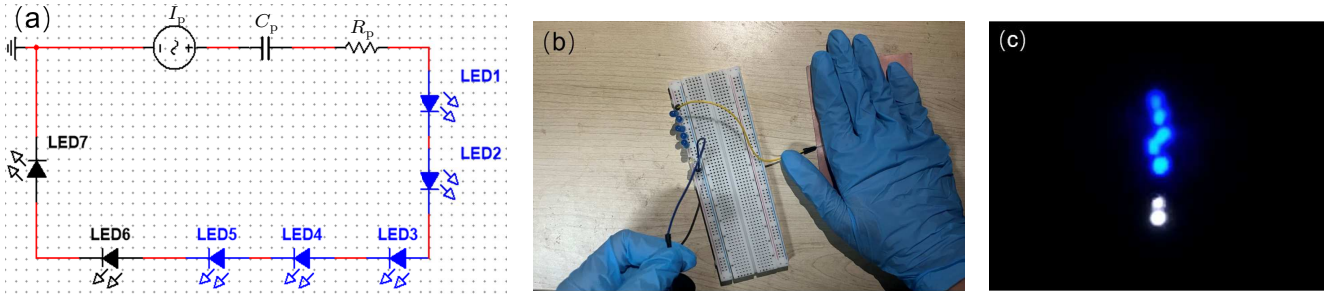


Fig. 4. Testing the power supply capability of the materials. (a) Circuit diagram for supplying energy to LEDs. (b) Photo of the TENG module used to power LEDs. (c) Illuminated diagram of LEDs after hand-tapping on the TENG.

clearly visible, indicating that the TENG could meet the power supply requirements. Thus, the application of flexible sensors in real life situations holds considerable promise.

The basic experiments in Subsections 2.1–2.3 confirm that the device is ready for the application-centered innovations of Morse code communication (Subsections 2.4) and array integration (Subsections 2.5).

2.4. Morse code transmission application based on a TENG

The origin of Morse code dates back to the 19th century, primarily serving long-distance communication and information transmission under extreme conditions. By the late 19th century, Morse code was recognized as the fastest means of transmitting messages over vast distances and it continues to be a significant method of information transmission in modern times. In this work a TENG is also used for transmitting Morse code. Morse code consists of two symbols: dots (·) and dashes (−). Specifically, one dot functions as a basic signal unit, with the duration of one dash being equivalent to three dots. Within a letter or number, the spacing between each dot or dash should be equivalent to the duration of two dots, while the spacing between letters or numbers should be seven dots in duration. According to the international Morse code table, the corresponding relationships between letters, numbers and symbols can be ascertained (Fig. 5(a)). Based on previous experiments, it has been established that varying tapping forces produce different voltage levels. Therefore, the high-voltage peaks can be used to represent dashes and low-voltage peaks to represent dots. Consequently, information encoded in Morse code can be transmitted as electrical output signals of a TENG. To decode the generated signals, the TENG is connected to an oscilloscope. Subsequently, the TENG is tapped with different levels of force to send a simple ”SOS” which signifies a distress signal (Fig. 5(c)). Observations indicate that the magnitude of the tapping force directly influences the generated voltage. Specifically, a higher voltage peak can be used to represent a dash while a lower voltage peak represents a dot in Morse code. Leveraging this principle, we can convey Morse code signals. To decode the generated signals, the TENG is connected to an oscilloscope. Subsequently, by applying varying degrees of force to tap the material, a simple “SOS” message, which signifies a distress signal, is sent (Fig. 5(c)).

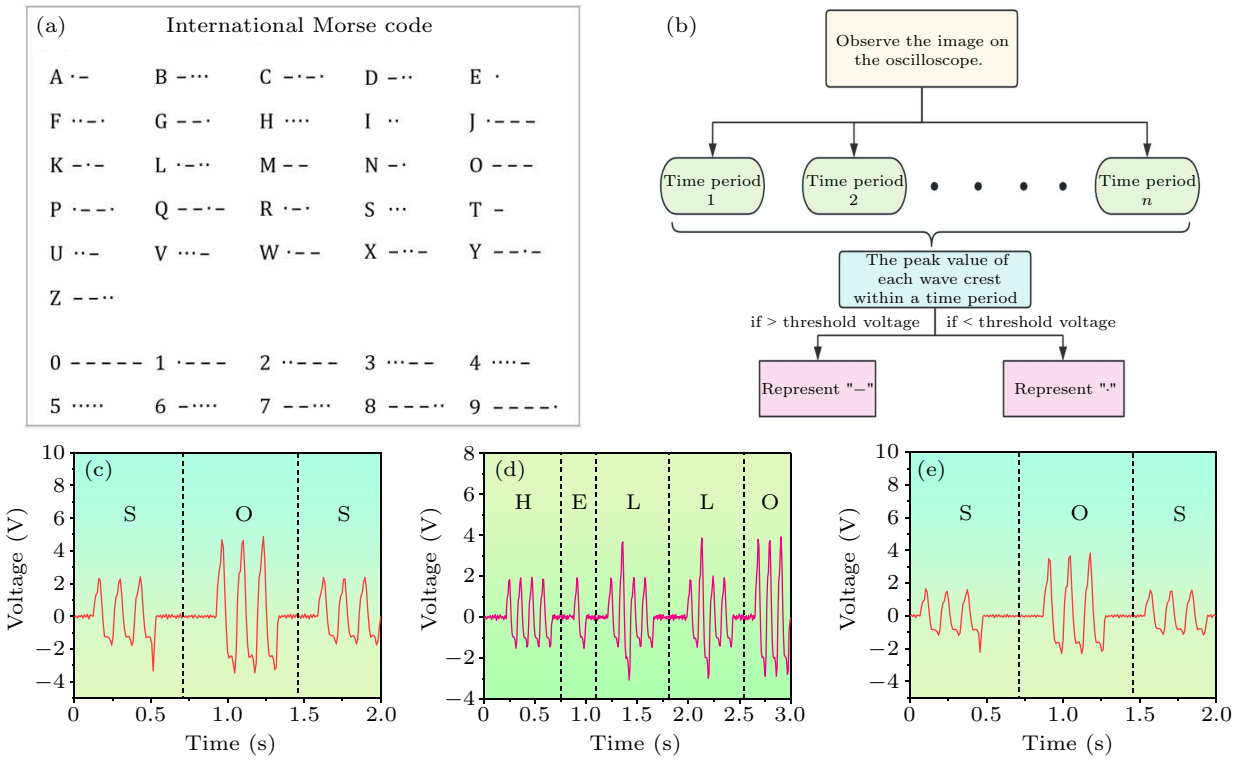


Fig. 5. Application of a friction nanogenerator (TENG) in a self-powered telegraph system. (a) International Morse code table. (b) Flowchart for decoding from oscilloscope waveforms. (c) Image of the electrical signal detected by the oscilloscope when sending the “SOS” message by tapping the material. (d) Image of the electrical signal detected by the oscilloscope when sending the “HELLO” message by tapping the material. (e) Image of the electrical signal detected by the oscilloscope when sending an “SOS” message by tapping the material after it has been placed under humid conditions for 1 week.

By observing the oscilloscope waveform, the average of all peak voltages across the various time periods was calculated to be approximately 3.8 V, which was then set as the threshold voltage. Subsequently, by following the method outlined in the decoding flowchart (Fig. 5(b)), the Morse code signal “···—···” can be readily derived. Finally, with reference to the international Morse code table, the signal is identified as “SOS”. More complex “HELLO” signals are sent

to demonstrate the reliability of using the TENG (Fig. 5(d)). Upon observing the oscilloscope image, the sent signal can also be directly decoded.

To test the impact of humidity in the experimental environment on the transmitted signals we placed the TENG in a high-humidity environment for 1 week. Then, we sent the signal "SOS" using the same method and under the same conditions. Observations of the waveform on the oscilloscope revealed a significant decrease in peak voltage of approximately 0.83 V (Fig. 5(e)). This suggests that humidity exerts some effect on the voltage of signals generated by the TENG. Nevertheless, the calculated threshold voltage remains capable of distinguishing waveforms, enabling ultimate decoding of the signal regardless of humidity conditions. This demonstrates its advantage in Morse code communication.

These experiments underscore the potential of a TENG as a Morse code generator, paving the way for its future development as a self-powered communication device and its application in the communication field.

2.5. Output performance of a 2×2 array

In this experiment a large square of material was initially cut into four identical pieces each capable of functioning as an independent signal sensor or energy harvesting device. Electrical output signals were recorded by tapping on these four pieces at different locations using fingers. Each piece was connected to one of the four channels of an oscilloscope to collect the respective output signals. Subsequently, when the same force was applied to impact two, three or all four pieces simultaneously they consistently responded rapidly and produced signals.

As shown in Fig. 6, the electrical output signals of the 2×2 array were systematically recorded. Figure 6(a) visually confirms the physical arrangement of four TENG units, which were separated by a spatial gap greater than 2 mm to ensure minimal interference. Figures 6(b) and 6(c) demonstrate the simultaneous activation of two channels (e.g., channels 1 and 2), where the output voltage peaks exhibit less than 5% amplitude deviation despite asynchronous tapping. Figures 6(d) and 6(e) capture three-channel operation (channels 1–3), highlighting signal uniformity with a crosstalk ratio of less than 3%. Finally, figure 6(f) validates full four-channel synchronization, where all units generate coherent signals under uniform pressure, proving the array's scalability for distributed sensing. Notably, the piece that was not tapped did not produce any signal output, confirming the absence of interference among the four small pieces. The slight variations in signals among different arrays could be attributed to slight differences in the impact force or internal structure as it was challenging to ensure an exactly uniform force. The experiment underscores the high degree of independence of this device and its potential applications in various self-powered sensing and energy harvesting scenarios.

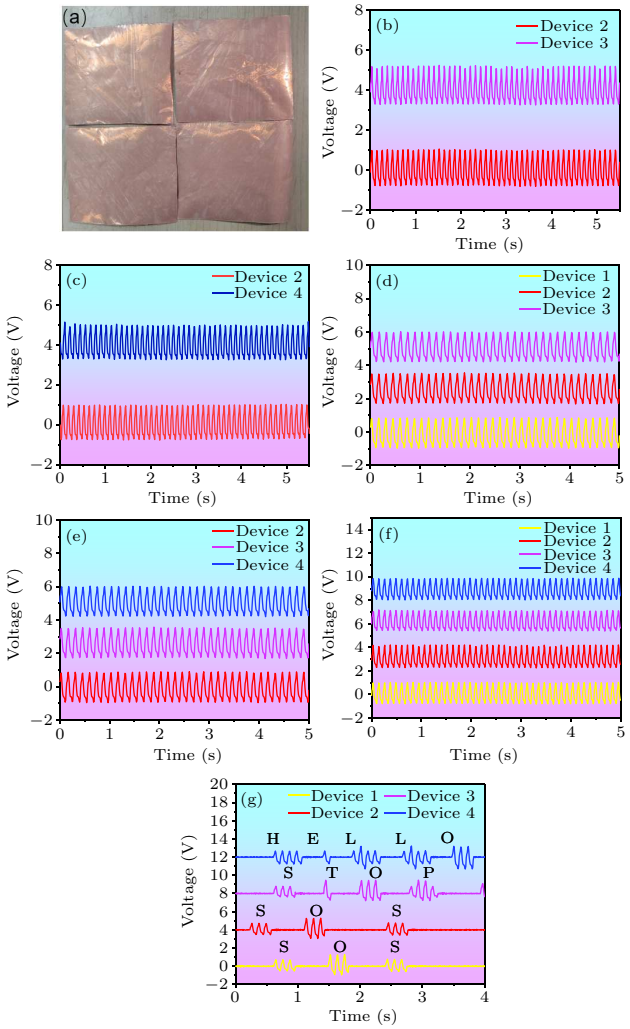


Fig. 6. Electrical output performance test of continuous pressing of a four-channel TENG. (a) Display of samples arranged in a 2×2 array. (b) and (c) Electrical signal image of two channels. (d) and (e) Electrical signal image of three channels. (f) Electrical signal image of four channels. (g) Waveform diagram of four-channel Morse code transmission signals.

To explicitly bridge the functional capabilities of Morse code transmission (Subsection 2.4) and array scalability (Subsection 2.5), we conducted experiments to validate the capacity of the 2×2 TENG array capacity for simultaneous multichannel Morse signaling. Each of the four array units was independently connected to an oscilloscope channel and programmed to transmit distinct Morse sequences with intentionally staggered initiation times: We transmitted the same Morse code sequence asynchronously: channel 1 was encoded as "SOS", while channel 2 sent "SOS" 488 ms in advance. Moreover, we also started transmitting different Morse codes simultaneously on the other two channels: channel 3 was encoded as "STOP" and channel 4 as "HELLO" (Fig. 6(g)). As can be observed from the images, all four channels maintained a signal fidelity exceeding 95% with crosstalk below 3%. The key points are as follows: the early transmitted SOS signal of channel 2 (green trace) showed almost no interference with the

baseline SOS signal of channel 1 (blue trace), which confirms their temporal decoupling; despite overlapping durations, the "STOP" signal of channel 3 (yellow) and the "HELLO" signal of channel 4 (purple) could still be decoded simultaneously without cross-channel interference; all channels followed a consistent voltage peak encoding logic (Figs. 5(a) and 5(b)), which verifies the uniformity of the protocol. This experiment conclusively establishes that the Cu/PTFE TENG array enables parallel, self-powered Morse communication — a critical advance for distributed sensing networks where multi-node coordination is essential, such as in emergency response systems transmitting location-specific alerts.

3. Conclusion

In summary, we have successfully crafted a simple and lightweight flexible sensor based on a TENG operating in single-electrode mode with PTFE film serving as the triboelectric layer. During the LED lighting experiment, the TENG exhibited remarkable output performance and power supply capabilities. Furthermore, its exceptional stability and application potential were confirmed through stability testing. Leveraging this sensor, we have developed a novel Morse code transmission system capable of real-time message transmission. Further, the telegraph signals "SOS" and "HELLO" were used to demonstrate successful wired transmission to another system, showcasing its vast application prospects in the field of communication. Additionally, through the investigation of a 2×2 array, the device's excellent independence and applicability were demonstrated in energy harvesting and self-powered sensing, showing promise for the development of sustainable devices and systems. Subsequently, by combining the Morse code transmission system with a 2×2 array, a self-powered array Morse code system has been successfully realized. In brief, the outstanding characteristics of this device demonstrate new methods for information transmission in the communication field and could find widespread use as a power supply and energy harvesting device in daily life.

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References

[1] Javaid S, Fahim H, Zeadally S, *et al.* 2023 *IEEE Sensors Journal* **23** 20483
[2] Wu S D, Dong P H, Cui X, *et al.* 2022 *Nano Energy* **96** 107136
[3] Zhao Z Q, Lu Y, Mi Y J, *et al.* 2022 *Micromachines* **13** 1586
[4] Yang Y G, Meng Y, Zeng Y H, *et al.* 2023 *Chin. Phys. B* **32** 090201
[5] Xie J H, Yang T and Tang J 2024 *Chin. Phys. B* **33** 050706
[6] Huang M L, Yang Y G and Liu Y 2024 *Chin. Phys. B* **33** 60203
[7] Zhang J Y, Gao Y K, Liu D, *et al.* 2023 *Nat. Commun.* **14** 3218
[8] Xia X, Fu J J and Zi Y L 2019 *Nat. Commun.* **10** 4428
[9] Sheng F F, Zhang B, Cheng R W, *et al.* 2023 *Nano Research Energy* **2** e9120079
[10] Guo X H, He J W, Zheng Y, *et al.* 2023 *Nano Research Energy* **2** e9120074
[11] Li H Z, Zhao X, Xie G Z, *et al.* 2025 *Appl. Phys. Lett.* **126** 053504
[12] Sun J F, Li J Q, Huang Y Z, *et al.* 2023 *Nano Research Energy* **2** e9120066
[13] Kurita K 2022 *Sensors* **22** 7161
[14] Zhou J M, Ma X T, Gao J Y, *et al.* 2024 *Small* **20** e2306980
[15] Huang J L, Cai Y L, Xie G Z, *et al.* 2024 *Wearable Electronics* **1** 180
[16] Liu H, Yang T H, Zhang Z X, *et al.* 2024 *High Voltage* **9** 1234
[17] Liu H, Zhang Z X, Song R M, *et al.* 2025 *Journal Lightwave Technology* **43** 6004
[18] Dai J, Xie G Z, Huo X H, *et al.* 2025 *Small* **21** 2407773
[19] Pan H, Wang Y X, Xie G Z, *et al.* 2025 *Journal of Composites Science* **9** 339
[20] Luo X L, Li W X, Yuan L, *et al.* 2024 *Nano Trends* **8** 100061
[21] Huang J L, Xie G Z, Xu X D, *et al.* 2024 *ACS Applied Materials & Interfaces* **16** 58838
[22] Li H Z, Yang S L, Xie G Z, *et al.* 2025 *ACS Applied Electronic Materials* **7** 1550
[23] Tan S X, Jiang Y, Chao X J, *et al.* 2025 *Nano Research* **18** 94907167
[24] Chandrasekhar A, Vivekananthan V, Khandelwal G, *et al.* 2019 *Nano Energy* **60** 850
[25] Liu H, Zhang Z X, Tian H Y, *et al.* 2024 *IEEE Transactions on Instrumentation and Measurement* **73** 9519612
[26] Li W X, Xie G Z, Huo X H, *et al.* 2025 *Journal of Materials Chemistry C* **13** 13582
[27] Li J, Xie G Z, Dai L W, *et al.* 2025 *Journal of Composites Science* **9** 123
[28] Sun L W, Shi W J, Tian X Q, *et al.* 2025 *NDT and E International* **151** 103318
[29] Hao H, Yao E J, Pan L, *et al.* 2025 *Transportation Research Part A* **199** 104525