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Perspective

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Three-dimensionally microarchitected electrospun fabric-enabled pressure-sensitive bioelectronics

Jia-Han Zhang[a,b,*], Jiawei Zhang[a], Xin Zhang[a,c], Xinrui Wang[a], Zhi Zhang[a], Xidi Sun[d], Haitao Wang[e], Zeng Liu[a,*], Ningning Sun[f], Lijia Pan[g,*]

1. Introduction

Bioelectronics, which enables the exchange of information, matter, and energy between electronics and biological systems, has emerged as a cornerstone of next-generation healthcare and physiological signal monitoring[1,2]. Among them, pressure-sensitive bioelectronics combine portability and wearability to enable convenient detection of multiple physiological signals, offering new opportunities for personalized healthcare and professional manipulation monitoring[3,4]. For comfortable, continuous, and long-term monitoring, pressure-sensitive bioelectronics demand lightweight breathable structures[5,6]. Electrospinning, a mature and cost-effective technique for producing porous fiber membranes with tunable thickness, has become the predominant strategy for fabricating pressure-sensitive materials[7]. In addition, electrospun fabrics provide broad material selectivity and ultrahigh surface area, maximizing the benefits of the materials to enhance and expand sensor functionalities[8]. Nevertheless, the random fiber stacking in conventional electrospun fabrics implies insufficient microstructural designability, limiting performance tunability across diverse applications[9]. Therefore, three-dimensionally (3D) microarchitected electrospun fabrics with optimized topology and geometric regularity have been developed to meet the stringent performance requirements in complex and extreme applications[10]. For example, electrospun micropyramid arrays (EMPAs) integrate high sensitivity, efficient radiative cooling, and excellent tactile transparency (ie, negligible tactile interference), enabling stable, precise monitoring of eSports players' fine manipulations and fingertip pulse in hot and humid environments[2]. Moreover, electrospun heterogeneous cancellous structures achieve high charge density while accelerating sweat evaporation and blocking external moisture ingress, endowing bioelectronics with high performance, wearing comfort, and stable operation under humid conditions[11]. This perspective summarizes recent progress in 3D microarchitected electrospun fabric-enabled pressure-sensitive bioelectronics, highlighting structural features, fabrication strategies, application potential, key challenges, and future directions (Figure 1).

2. Electrospun pressure-sensitive bioelectronics

Pressure-sensitive bioelectronics build a critical bridge between mechanical physiological stimuli and electrical signals, enabling quantitative interpretation of biological mechanical information through diverse sensing mechanisms. According to sensing mechanisms, pressure-sensitive bioelectronics can be classified into 7 types: (i) piezocapacitive, (ii) piezoresistive, (iii) iontronic, (iv) piezoelectric, (v) triboelectric, (vi) flexoelectric, and (vii) electret[1]. Piezocapacitive and piezoresistive sensors transduce external mechanical stimuli into electrical signals, where deformation of the sensitive layer leads to variations in capacitance (C) or resistance (R). They are respectively governed by the following two equations:

$$C = \frac{\varepsilon_r \ \varepsilon_0 A}{d} \tag{1}$$

$$R = \frac{\rho L}{A'}, \tag{2}$$

where ε_0 is the dielectric constant in a vacuum, ε_r is the relative dielectric constant, A is the electrode area, d is the thickness of the sensitive layer, ρ is the resistivity, L is the length, and A' is the contact area. Accordingly, to pursue high sensitivity, micro-/nanoarchitectured low-modulus elastomers are typically employed as the sensitive layer[2,10]. Under a given pressure, such layers undergo larger deformations, resulting in more pronounced variations in the physical parameters described in Equations (1) and (2). The iontronic sensor shares a structural similarity with the conventional piezocapacitive device. Compared with the piezocapacitive sensor, its key distinction lies in the nanometer-thick electric double layer at the electrolyte–electrode interface, which can enhance the unit areal capacitance by more than 3 orders of magnitude, thereby markedly improving sensitivity. This unique feature even enables precise detection of subtle force variations

[a]School of Electronic Information Engineering, Electronic-Photonic Smart Sensing Device R&D Team, Inner Mongolia Key Laboratory of Intelligent Communication and Sensing and Signal Processing, Inner Mongolia University, Hohhot, China, [b]Inner Mongolia BKJD Robot Co., Ltd., Baotou, China, [c]School of Life Sciences, Inner Mongolia University, Hohhot, China, [d]Institute for Health Innovation & Technology (iHealthtech), National University of Singapore, Singapore, Singapore, [e]Center for Integrated Research of Future Electronics, Institute of Materials and Systems for Sustainability, Nagoya University, Nagoya, Japan, [f]School of Materials Science and Engineering, Inner Mongolia University of Science and Technology, Baotou, China,[g]Collaborative Innovation Center of Advanced Microstructures, School of Electronic Science and Engineering, Nanjing University, Nanjing, China

*Corresponding authors: Address: Jia-Han Zhang, School of Electronic Information Engineering, Electronic-Photonic Smart Sensing Device R&D Team, Inner Mongolia Key Laboratory of Intelligent Communication and Sensing and Signal Processing, Inner Mongolia University, Hohhot 010021, China; E-mail address: JiaHan_Zhang@outlook.com, (J.-H. Zhang); Zeng Liu, School of Electronic Information Engineering, Electronic-Photonic Smart Sensing Device R&D Team, Inner Mongolia Key Laboratory of Intelligent Communication and Sensing and Signal Processing, Inner Mongolia University, Hohhot 010021, China; E-mail address: zengliu@imu.edu.cn (Z. Liu); Lijia Pan, Collaborative Innovation Center of Advanced Microstructures, School of Electronic Science and Engineering, Nanjing University, Nanjing 210093, China; E-mail address: ljpan@nju.edu.cn (L. Pan).

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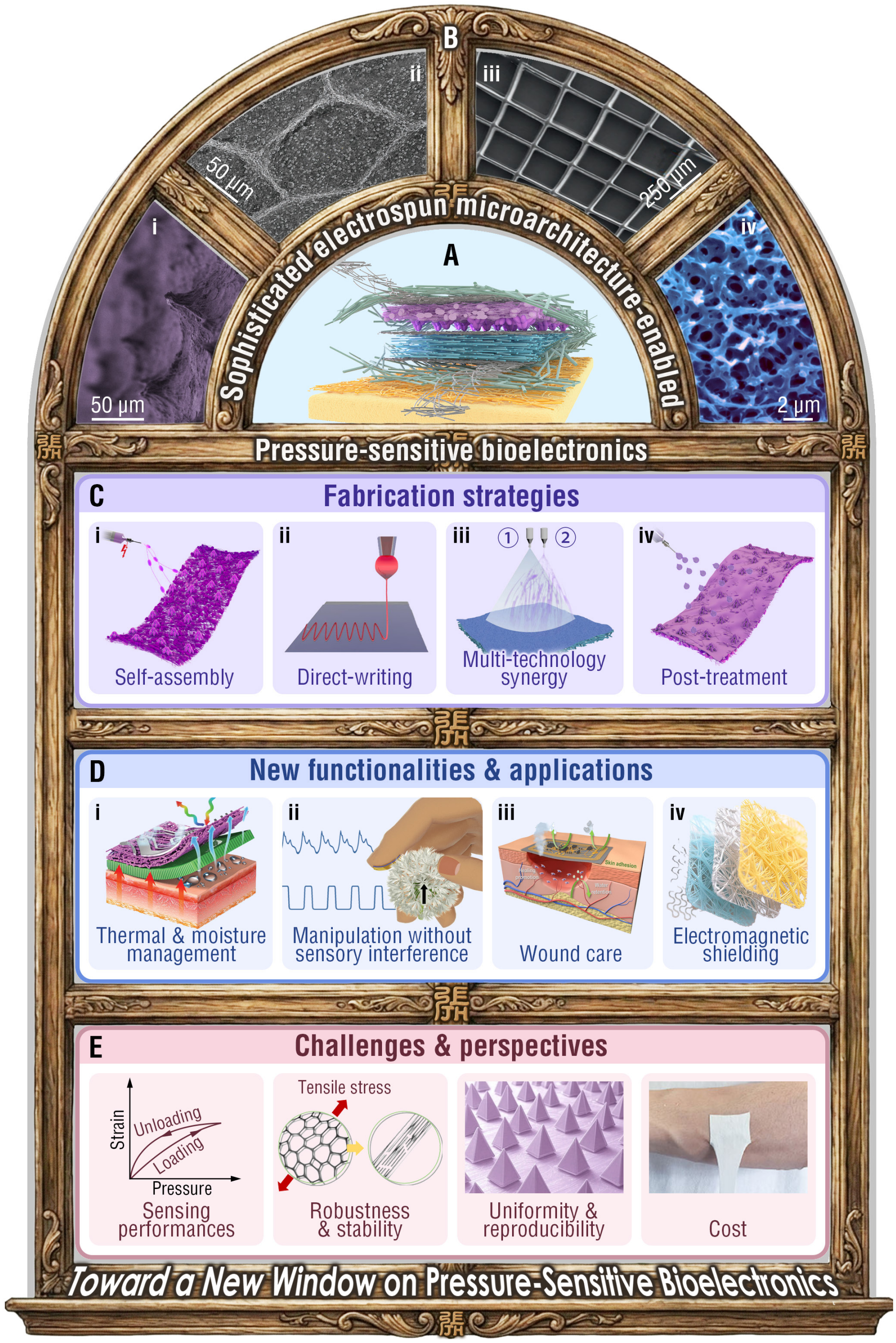

Fig. 1. Summary of 3D microarchitected electrospun fabrics, fabrication strategies, and applications of pressure-sensitive bioelectronics. (A) Schematic diagram of a typical electrospun pressure sensor. (B) SEM images of four 3D microarchitected electrospun fabrics[2,7,10,11]: (i) micropyramid array, (ii) honeycomb-like array, (iii) grid wall, and (iv) cancellous-bone-like structure. (C) Schematic diagrams of 4 typical fabrication strategies[9,12,13]: (i) self-assembly, (ii) direct-writing, (iii) multi-technology synergy, and (iv) post-treatment. (D) Schematic diagrams of new functionalities and applications[7,8,14,15]: (i) moisture and thermal management, (ii) manipulation without sensory interference, (iii) wound care, (iv) electromagnetic shielding. (E) Schematic diagrams of challenges and perspectives[12].

under preloaded pressure conditions. The common advantage of piezocapacitive, piezoresistive, and iontronic sensors is their high stability and accuracy in detecting static forces, a feature that has already enabled commercialization. However, their limitation is the relatively slow response time, typically ranging from tens to several hundreds of milliseconds, which makes precise monitoring of dynamic forces challenging.

In contrast to the above 3 types of sensors, piezoelectric, triboelectric, and flexoelectric sensors rely on Maxwell's displacement current and perform self-powered sensing by converting mechanical signals into electrical signals. Their response times are on the nanosecond scale, making them particularly suitable for monitoring dynamic forces[13]. Moreover, Equations (3)–(5) describe the characteristics and determining factors of their outputs.

$$V_{\mathrm{PE}} = \frac{d_{33} dT}{\varepsilon_0 \ \varepsilon_{\mathrm{r}}} \tag{3}$$

$$V_{\mathrm{TE}} = -\frac{Q}{A\varepsilon_0}\left[\frac{d_1}{\varepsilon_{\mathrm{r2}}} + \frac{d_2}{\varepsilon_{\mathrm{r2}}} + x(t)\right] + \frac{\sigma x(t)}{\varepsilon_0} \quad (4)$$

$$P_{\mathrm{FE}} = \mu_{\mathrm{ijkl}} \frac{\partial T_{\mathrm{ij}}}{\partial x_{\mathrm{k}}}, \quad (5)$$

where V_{PE} is the open-circuit voltage of the piezoelectric sensor, d_{33} is the piezoelectric coefficient, T is the applied stress, V_{TE} is the output voltage of the triboelectric sensor, Q is the total free charge on the electrode, subscripts 1 and 2 correspond to different tribolayers, x is the distance between a pair of tribolayers, σ is the surface tribocharge density, P_{FE} is the flexoelectric polarization, μ_{ijkl} is the flexoelectric coefficient, T_{ij} is the elastic strain, and x_k is the position coordinate. Notably, the fundamental origin of the piezoelectric displacement current is the noncentrosymmetric positive and negative charges within unit cell planes. Accordingly, ferroelectric ceramic particles and polymers are usually polarized and then employed to fabricate flexible piezoelectric sensors. The triboelectric displacement current arises from the coupled effects of contact electrification and electrostatic induction. This interfacial effect is primarily determined by the effective contact area and polarity differences of the tribo-materials. Due to the ubiquity of contact electrification, triboelectric sensors offer a broad range of material options. Flexoelectric displacement current is induced by a strain gradient or a nonuniform strain field that locally breaks the inversion symmetry of the material. Consequently, the flexoelectric effect is size-dependent and becomes particularly significant at the nanoscale. Besides, electret sensors operate by local potential changes in the device when pressure is applied to the electret material. Since they often couple piezoelectric and triboelectric effects, their output characteristics are similar to those of piezoelectric and triboelectric sensors.

Electrospinning, as an additive manufacturing technique for microarchitected fabrics, is highly suitable for constructing pressure-sensitive bioelectronics (Figure 1A). For piezocapacitive and piezoresistive sensors, the porous structure of electrospun fabrics significantly reduces the compressive modulus, thereby enhancing device sensitivity[2]. In terms of piezoelectric sensors, the in-situ poling effect during electrospinning aligns dipoles, directly activating the piezoelectricity of the device[1]. For triboelectric sensors, the rough surface of electrospun fabrics increases the effective contact area, thus improving sensing performances (eg, detection limit, sensitivity)[11]. In terms of flexoelectric sensors, the diameter of the electrospun fibers ranges from the micro- to nanometer scale. With appropriate fiber stacking, these micro/nanofibers can effectively activate and enhance the flexoelectric response of the sensor[1]. For electret sensors, the pores formed by the interlaced electrospun electret fibers act as pore dipoles, which can enhance the sensor's response to external pressure[14]. Beyond traditional microstructures, some 3D microarchitected electrospun structures, featuring unique mechanical and electrical properties, offer greater advantages in optimizing the performance of pressure-sensitive bioelectronics[2]. These will be discussed in the next section.

3. 3D microarchitected electrospun pressure-sensitive fabrics

As the core component of electrospun pressure-sensitive bioelectronics, functional fabrics play a decisive role in enabling multifunctional integration and overall device performance. Conventional electrospun fabrics are thin-film structures that are typically composed of randomly interlaced electrospun fibers. Regardless of whether the fibers are uniform, bead-on-string, porous, hollow, wire-in-tube, or multi-channel-tubes, their surfaces are relatively smooth, with a roughness generally below 1 μm[14]. In contrast, 3D microarchitected electrospun fabrics refer to microstructures with highly ordered arrangements and unit dimensions exceeding 1 μm (eg, EMPAs, [Figure 1B-i][2], electrospun honeycomb-like arrays [Figure 1B-ii][7], and electrospun grid wall arrays[10] [Figure 1B-iii]), or those with topological features that differ significantly from conventional electrospun fabrics (eg, electrospun cancellous structures[11] [Figure 1B-iv]). These 3D microarchitected electrospun fabrics not only retain the inherent advantages of conventional electrospun fabrics but also provide significant enhancements in multiple performances of bioelectronics. For example, EMPAs feature gradient space filling, gradient stress distribution, and gradient refractive index, enabling excellent regulation of force, heat, light, and electricity. As a result, EMPA-based pressure sensors not only exhibit outstanding sensing performance (sensitivity ~19 kPa^{-1}, detection limit ~0.05 Pa, response time ~0.8 ms), but also demonstrate remarkable radiative cooling capability (temperature drop ~4 °C), which helps prevent skin perspiration and thereby enhances sensing stability[2].

3D microarchitected electrospun fabrics can be fabricated by 4 typical strategies: (1) self-assembly, (2) direct-writing, (3) multi-technology synergy, and (4) post-treatment. Self-assembly refers to the technique in which fibers, driven by Coulomb force, surface tension, and other forces during far-field electrospinning, are not randomly stacked but instead organized into ordered microarchitectures (Figure 1C-i)[2]. For example, Zhang's group develops an electrostatic jet self-assembly technology to fabricate various breathable 3D microarchitected fabrics in a single-step process[2]. This strategy takes advantage of the slow evaporation of low-saturated vapor pressure solvents in precursor solutions, leaving residual solvent in the droplet or jet. The residual solvent tunes the jet's electrohydrodynamics, thereby controlling its geometric structure, charged state, and aggregation state on the collector, and enabling the precise construction of diverse pressure-sensitive microarchitectures[2,11,13-15]. For high-concentration precursor solutions (typically >10 wt%), the residual solvent acts as a sacrificial template, enabling the fabrication of heterogeneous, homogeneous, or gradient porous microarchitectures with interconnected topology, such as the interconnected cancellous structure (Figure 1B-iv). The pores of these microstructures typically range from tens of nanometers to the submicron scale[11,14,15]. In contrast, for low-concentration precursor solutions (typically ≤10 wt%), the charged residual solvent induces heterogeneous charged microdomains that, via electrostatic and related interactions, regulate subsequent jet aggregation state[2,13]. This strategy is used to fabricate microarray structures, such as microprotrusion and micropyramid arrays (Figure 1B-i). The unit structures of these microarrays typically range from a few micrometers to several thousand micrometers[2]. Thanks to its high efficiency and low cost, self-assembly is the most widely used technique for producing 3D microarchitected electrospun fabrics.

Direct writing utilizes medium- or near-field electrospinning to precisely control the trajectory of a single jet, enabling the fabrication of highly ordered microarchitectures (Figure 1C-ii). When a variable deflecting field is applied to the moving jet via aerial electrodes, jet instabilities are suppressed[16]. This enables the fabrication of extremely complex microstructures with submicrometer features, similar to 3D printing. The advantages of direct writing include high design flexibility and fabrication accuracy, while its main limitation is low production efficiency. Multi-technology synergy integrates different types of charged jet processing techniques to simultaneously deposit jets with distinct morphologies onto a single electrospun film, thereby forming 3D microarchitected electrospun structures (Figure 1C-iii). For example, the combination of electrospinning and electrospraying can produce hierarchical micro-nanoprotrusions[9]. Post-treatment refers to subsequent processing of as-prepared electrospun fabrics to optimize their geometric or topological structures (Figure 1C-iv). For instance, nanoimprinting can introduce 3D microarchitecture arrays on the surface, while solvent welding can produce topologically interconnected microarchitectures[13].

4. Emerging functionalities and applications

To meet the increasing demands for sensing precision and functional integration in pressure-sensitive bioelectronics, 3D microarchitected electrospun fabrics have emerged as a powerful structural platform. A key advantage of 3D microarchitected electrospun fabrics lies in their ability to both enhance sensing performance and expand device functionality. On the one hand, their unique physical properties achieve effective optimization of sensitivity, response time, hysteresis, detection limit, and linearity. For instance, gradient 3D electrospun microarchitectures with gradient stress distribution enable larger compressive deformation, thereby improving sensitivity and decreasing the detection limit. Drawbacks of slow response and large hysteresis, arising from friction energy dissipation of electrospun fibers, can be mitigated by tailoring microstructural topology. Specifically, bridging the potential contact interfaces of electrospun fibers into an integrated microarchitecture minimalizes possible friction. Moreover, high linearity can be realized by introducing spherical hierarchical micro-nanostructures, which benefits from the highly linear relationship between the microarchitecture-electrode contact area and the applied load. On the other hand, 3D microarchitected electrospun fabrics provide devices with new functionalities, including (1) moisture and thermal management, (2) manipulation with negligible sensory interference, (3) wound care, and (4) electromagnetic shielding.

The moisture and thermal management capability of 3D microarchitected electrospun fabrics is attributed to their mechanical, thermal, and optical regulation properties. For low-surface-energy electrospun structures, trapped air within the microarchitectural gaps generates elastic repulsion against water droplets, enabling superhydrophobicity and preventing external moisture ingress. Furthermore, Janus or gradient pore-size designs can establish a wettability gradient force and capillary pressure gradient, enabling unidirectional water/moisture transport. During water/sweat transport, heat transfer naturally occurs as well. Introducing high-thermal-conductivity materials into electrospun fibers to form interpenetrated networks further enhances heat dissipation[17]. In addition to heat conduction, heat radiation is also an important mode of heat transfer. Some 3D electrospun microarchitectures function as meta-surface photonic crystals, with tailored fiber diameters and geometries that enhance Mie scattering and mid-infrared emissivity[18], achieving efficient radiative cooling (Figure 1D-i).

Tactile-transparent sensors minimally affect the user's tactile perception, allowing sensing of their presence without disrupting perception of the object's critical features, similar to visual transparency. They facilitate understanding and reproducing natural behaviors without sensory interference, playing an important role in fine-manipulation monitoring and limb functional rehabilitation (Figure 1D-ii). 3D microarchitected electrospun fabrics are ideal candidates for such devices. These 3D microarchitected electrospun sensors are breathable, ultrathin, and exhibit extremely low contact stiffness, allowing them to conform seamlessly to skin textures without interfering with the natural deformation of cutaneous mechanoreceptors, thus ensuring tactile transparency. More importantly, the 3D microarchitected electrospun fabrics endow these sensors with sensing performances comparable to lithographically patterned microstructured devices, ensuring practicality while broadening application scenarios. For instance, EMPA-based high-performance tactile-transparent sensors can detect fingertip pulse, fine manipulations, and emotional states of eSports players, enabling skill-level assessment[6].

Wound care and electromagnetic shielding are 2 other crucial applications enabled by 3D microarchitected electrospun fabrics. Through the integration of various functional materials, their highly porous and breathable fibrous networks provide an optimal moist and gas-permeable environment that accelerates tissue regeneration while preventing external bacterial invasion. Moreover, functional components such as antibacterial agents, growth factors, or conductive fillers can be directly incorporated into electrospun fibers, allowing controlled and stimuli-responsive drug release. Such microarchitectured wound dressings not only accelerate recovery but also minimize infection risk, representing a paradigm shift from passive protection to active, intelligent wound management[19]. Additionally, in terms of electromagnetic shielding, electrospun microarchitectures with conductive fillers such as metal nanoparticles, carbon nanomaterials, or MXenes can form continuous and interconnected networks that effectively attenuate electromagnetic radiation through reflection, absorption, and multiple scattering. The electrospun networks not only enhance the shielding effectiveness by extending the propagation pathways of electromagnetic waves but also maintain lightweight, breathable, and mechanically robust properties. This ensures the reliable and stable operation of pressure-sensitive bioelectronics in complex electromagnetic environments[8].

5. Challenges and perspectives

3D microarchitected electrospun fabrics have unlocked diverse functionalities and applications in pressure-sensitive bioelectronics. Nevertheless, challenges in (1) sensing performance, (2) robustness and stability, (3) uniformity and reproducibility, and (4) cost persist (Figure 1E). Overcoming these could pave the way for transformative innovations and impactful applications.

First, the response time and hysteresis performances of electrospun piezocapacitive and piezoresistive bioelectronics still lag behind lithographically patterned microstructured sensors, although 3D microarchitected electrospun fabrics have enabled breakthroughs in sensitivity and detection limits. This limitation arises from energy dissipation caused by inter-fiber contact friction. A promising strategy is to employ advanced electrospinning techniques to optimize the geometry and topology of the microarchitectures, which can reduce interfacial contact and minimize friction. Second, compared with dense film-based devices, fibrous electrospun bioelectronics exhibit lower robustness and stability. A possible solution is to construct more topological interconnections within 3D electrospun microarchitectures to mitigate interlayer delamination and local stress concentrations that may lead to structural failure. Third, the inherent instability of charged jets makes it challenging to achieve high uniformity across different batches of 3D electrospun microarchitectures. Even within the same batch, it is difficult to ensure that each microstructural unit is identical. This variability limits the industrialization of 3D microarchitectured electrospun bioelectronics. Consequently, strict control of processing parameters, such as electric field strength, temperature, and humidity, is required to maximize uniformity and reproducibility. Finally, in practical applications, electrospun bioelectronics often require intimate adhesion to the skin using adhesives, which can damage 3D microarchitected electrospun fabrics upon removal. Their disposable feature increases costs. Therefore, it is necessary to develop more cost-effective materials for producing 3D microarchitectured electrospun pressure-sensitive bioelectronics.

Overall, 3D microarchitected electrospun fabric-enabled pressure-sensitive bioelectronics represent a powerful and versatile platform that bridges advanced structural design with multifunctional bioelectronic performance. By rationally engineering microarchitectural geometry and topology, these systems offer unique advantages in sensing performance enhancement, functional integration, and application adaptability that are difficult to achieve with conventional electrospun fabrics. Although challenges remain in stress-strain mismatch, mechanical robustness, large-area uniformity, and cost-effective manufacturing, continued advances in electrospinning technologies, structural design strategies, and materials innovation are expected to drive this field toward scalable fabrication and real-world deployment.

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Conflicts of interest

The authors declare that they have no conflict of interest.

Author contributions

Jia-Han Zhang conceived, organized, and wrote the manuscript. Jia-Han Zhang, Ningning Sun, Xidi Sun, Haitao Wang, Zhi Zhang, Jiawei Zhang, Xinrui Wang, and Xin Zhang. contributed to picture plotting. Lijia Pan and Zeng Liu supervised the perspective. All authors discussed and approved the final manuscript.

References

[1] Zhang J-H, Li Z, Liu Z, et al. Inorganic dielectric materials coupling micro-/nanoarchitectures for state-of-the-art biomechanical-to-electrical energy conversion devices. *Adv Mater*. 2025;37:e2419081.
[2] Zhang J-H, Li Z, Xu J, et al. Versatile self-assembled electrospun micropyramid arrays for high-performance on-skin devices with minimal sensory interference. *Nat Commun*. 2022;13:5839.
[3] Shin D, Kim S, Park H, et al. Soft Schottky diodes for skin-interfaced electronics enabled by entirely soft components. *Soft Sci*. 2024;4:22.
[4] He J, Lyu T, Song D, et al. A universal orientation-engineering strategy for enhancing mechano-electric conversion performance in semicrystalline biopolymers. *Adv Mater*. 2025;37:e10157.
[5] Dong K, Zhang Y, Fan X, et al. Microfiber-based triboelectric acoustic sensors enable self-powered ultrasonic localization and tracking underwater. *ACS Sens*. 2025;10:1366–1377.
[6] Zhao J, Fan X, Xie H, et al. Revolutionizing wearable sustainable energy enabled by mechano-electric conversion fibers. *Energy Environ Sci*. 2025;18:3955–3985.
[7] Zhang Y, Fu J, Ding Y, et al. Thermal and moisture managing e-textiles enabled by Janus hierarchical gradient honeycombs. *Adv Mater*. 2024;36:2311633.
[8] Peng Y, Song J, Zhang Y, et al. Permeable, wet-adhesive, and EMI-resistant liquid metal electronic skin for high-fidelity electrophysiological monitoring in sweaty and electromagnetic environments. *Adv Mater*. 2025;37:e08041.
[9] Ge J, Zong D, Jin Q, et al. Biomimetic and superwettable nanofibrous skins for highly efficient separation of oil-in-water emulsions. *Adv Funct Mater*. 2018;28:1705051.
[10] Huang Y, You X, Tang Z, et al. Interface engineering of flexible piezoresistive sensors via near-field electrospinning processed spacer layers. *Small Methods*. 2021;5:2000842.
[11] Zhang J-H, Li Y, Du J, et al. Bio-inspired hydrophobic/cancellous/hydrophilic trimurti PVDF mat-based wearable triboelectric nanogenerator designed by self-assembly of electro-pore-creating. *Nano Energy*. 2019;61:486–495.
[12] Zhang S, Liu H, Yu J, et al. Multi-functional flexible 2D carbon nanostructured networks. *Nat Commun*. 2020;11:5134.
[13] Zhang J-H, Li Z, Shen B, et al. Electric displacement modulation under internal field for high-performance mechanical-to-electrical energy generator. *Cell Rep Phys Sci*. 2024;5:102025.
[14] Zhang J-H, Zhou Z, Li J, et al. Coupling enhanced performance of triboelectric–piezoelectric hybrid nanogenerator based on nanoporous film of poly(vinylidene fluoride)/batio$_3$ composite electrospun fibers. *ACS Materials Lett*. 2022;4:847–852.
[15] Zhang J-H, Li Y, Hao X. A high-performance triboelectric nanogenerator with improved output stability by construction of biomimetic superhydrophobic nanoporous fibers. *Nanotechnology*. 2020;31:215401.
[16] Liashenko I, Rosell-Llompart J, Cabot A. Ultrafast 3D printing with submicrometer features using electrostatic jet deflection. *Nat Commun*. 2020;11:753.
[17] Miao D, Wang X, Yu J, et al. A biomimetic transpiration textile for highly efficient personal drying and cooling. *Adv Funct Mater*. 2021;31:2008705.
[18] Liu J, Zhai H, Li J, et al. Enhancing wearable electronics through thermal management innovations. *Wearable Electr*. 2024;1:160–179.
[19] Huang X, Zhang Q, Yang Y, et al. A skin-interfaced three-dimensional closed-loop sensing and therapeutic electronic wound bandage. *Nat Commun*. 2025;16:5782.

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