

REVIEW

Recent progress in covalent organic frameworks for flexible electronic devices

Jinghang Wu¹ | Shiwei Zhang¹ | Qianfeng Gu¹  | Qichun Zhang^{1,2}

¹Department of Materials Science and Engineering, City University of Hong Kong, Hong Kong SAR, China

²Department of Chemistry, Center of Super-Diamond and Advanced Films (COSDAF) & Hong Kong Institute of Clean Energy (HKICE), City University of Hong Kong, Hong Kong SAR, China

Correspondence

Qichun Zhang.
Email: qiczhang@cityu.edu.hk

Funding information

Innovation and Technology Fund, Grant/Award Number: ITS/322/22; Jinlin University, Grant/Award Number: sklssm2024039; City University of Hong Kong, Grant/Award Numbers: 9380117, 7020089

Abstract

Covalent organic frameworks (COFs) are porous materials with good crystallinity, highly ordered stacking, tunable channels, and diverse functional groups that have been demonstrated to show great potential applications in flexible electronic devices, including flexible energy storage devices (batteries and supercapacitors), memristors and sensors. Although great research progress on the usage of COFs as active elements in flexible electronics has been witnessed, the summary in this direction is rare. Thus, it is the right time to write a review on COFs-based flexible electronics. In this review, we will first discuss the different synthesis strategies to prepare COF materials. Then, the applications of COFs in flexible electronic devices are summarized. Finally, the future performance improvement and development directions of COFs in the field of flexible electronic devices are briefly outlined. This review could provide basic concepts and some guidelines to stimulate novel applications of COFs in diverse flexible electronic devices.

KEYWORDS

batteries, covalent organic frameworks, electronic devices, flexibility, memristors, sensors, supercapacitors

1 | INTRODUCTION

In recent years, flexible electronic devices have attracted extensive attention from the scientific research and industrial communities due to their excellent mechanical flexibility, lightweight and high-strength structural features.^{1–7} Flexible devices can be seamlessly integrated with the human-machine environment, showing broad application prospects in the fields of wearable electronic devices, human-computer interaction systems, electronic skin and biomedical devices.^{8,9} In practical applications, devices need to withstand changing environmental

conditions, mechanical stresses and chemical substances.^{10–12} Therefore, the development of new functional materials to meet the multi-faceted requirements is currently a popular research topic. However, inorganic materials and inorganic-organic hybrid materials, used for flexible electronic devices, have certain limitations.¹³ Inorganic materials are generally more brittle and require higher preparation temperatures. In contrast, inorganic-organic hybrid materials face several challenges, such as poor interfacial compatibility and complex synthesis processes. Besides, both types of materials have the disadvantages of high cost and environmental unfriendliness. In

This is an open access article under the terms of the [Creative Commons Attribution](https://creativecommons.org/licenses/by/4.0/) License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.

© 2024 The Author(s). FlexMat published by John Wiley & Sons Australia, Ltd on behalf of Nanjing University of Posts & Telecommunications.

addition, some organic materials have weak thermal and chemical stability, which is not suitable for some operating environments of flexible electronic devices.^{14,15} Therefore, finding a material with high stability, environmental friendliness and low cost is crucial for the future development of flexible electronic devices.

Among all organic materials for flexible electronics, covalent organic frameworks (COFs) have attracted substantial attention as one type of emerging porous crystalline organic material with high thermal and chemical stability.^{16,17} They are made from small organic building units connected through covalent bonds with good crystallinity, high porosity, high specific surface area (SSA), high tunability and structural diversity.^{18–22} COFs have been shown to have a wide range of applications in various disciplines, such as catalysis, energy storage and conversion, optoelectronics, and chemical sensing.^{23–33} Their success in multidisciplinary applications holds promise for providing new research opportunities. Although low conductivity and poor processability might restrict COFs in flexible electronic device applications,^{34,35} the recent advance in developing different strategies to fabricate COF films various flexible devices, especially for flexible energy storage devices, has been witnessed.

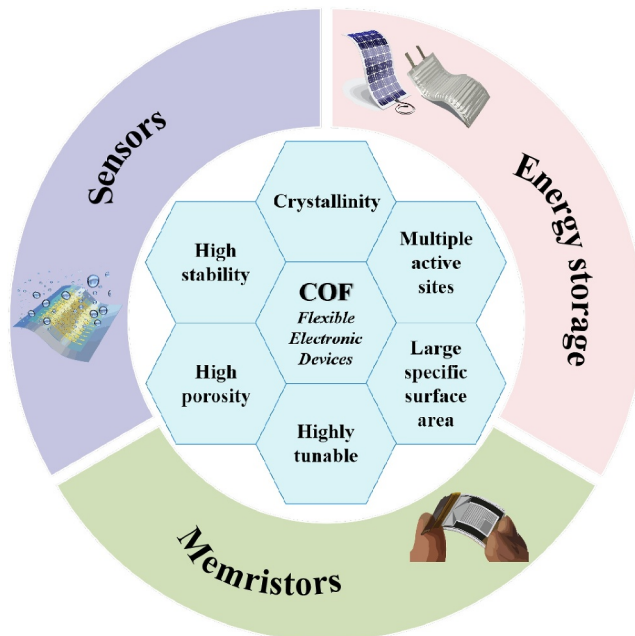
In this review, we first summarize the synthesis strategies of COF materials. Then, the applications of COFs in flexible energy storage devices, data storage devices and sensor devices are discussed. Finally, an outline of the future development as well as novel potential applications of COFs are provided. We believe that an in-depth exploration of the applications of COF in the field of flexible devices will help promote the advancement of flexible electronics technology. This lays the foundation for realizing the commercial application of next-generation flexible electronic devices (Scheme 1).

2 | SYNTHESIS OF COF MATERIALS

The synthesis of COFs and the subsequent fabrication of COF-based films are pivotal steps for their applications in flexible electronic devices. Typically, COFs were obtained as powders through solvothermal methods, where organic monomers could be linked together through imine, boronate ester or other bonds to form two-/three-dimensional networks.³⁶ To incorporate COFs into flexible devices, several ways to prepare COF-based thin films have been reported, which are summarized as follows.

2.1 | Powder-pressing method

Pre-synthesized COF powders can be transformed into films using a hydraulic press under controlled



Scheme 1 Basic properties of COFs and the three kinds of flexible electronic devices developed based on them.

pressure.^{37,38} For example, Xu et al. demonstrated the fabrication of crystalline COF films from powder through the application of an uniaxial hydraulic press at 150°C. This method enhances its mechanical strength and induces preferential orientation along the (001) facet, thereby rendering the films advantageous for deployment as solid-state electrolytes in flexible battery systems.³⁹ However, the intrinsic low conductivity of COFs limits the applicability of this method for other electronic devices.⁴⁰

2.2 | Fabrication of COF composites

The incorporation of conductive supporting materials, such as graphene,^{41,42} carbon nanotubes,^{43–48} MXenes,^{49,50} or conductive polymers,^{51–54} into COFs is a prevalent strategy to improve their mechanical properties and electrical conductivity. These composite films can be prepared by simply blending COF powders with the desired additives. Besides, a flexible, freestanding thin composite film with excellent conductivity and an ordered pore structure can be obtained through electrostatic self-assembling.^{43,44,49,50} In addition to self-assembling, Kaskel and Zhao et al. used a one-step self-templated strategy to grow polypyrrole (PPy) on the COF surface or in the pores to obtain high-quality films.^{52,53} Moreover, in situ growth of COF on the surface of conductive carbon materials has also been proven to be a good method to obtain films with good flexibility.^{45–48} For example, the intermolecular π - π interaction between the surface of reduced graphene oxide (rGO) and COF enhances the robustness of the as-obtained films.^{41,42}

2.3 | Solution-processable COFs

The covalently connected nature of COFs generally renders them insoluble in most solvents, limiting their solution processability. However, the solubility and dispersibility of COFs in various solvents can be improved by judicious design of monomer structures and reaction conditions or through exfoliation strategies. These methods enable solution-based deposition techniques like spin-coating or dip-coating.^{55–59} Besides, the protonation of COF linkages by strong acid allows it to be dispersed into several layers of films in the solution. Then, the COF film could be obtained by drop-casting and shows good electronic performance.⁵⁸ Liu and Yuan et al. introduced well-designed building blocks into COFs. The film obtained by the chlorobenzene solutions plays a passivation role in perovskite solar cells.^{56,59} Moreover, uniform COF films can also be peeled off and grown by electrochemical methods.^{55,57}

2.4 | Interfacial growth

Direct growth of COF films can be achieved through interfacial polymerization reactions at liquid-liquid,^{60,61} gas-liquid,^{62–66} or solid-liquid interfaces.⁶⁷ By carefully controlling the reaction conditions and dynamics at these interfaces with templates, high-quality COF films constructed with irreversible linkers can be formed in situ at these interfaces. Feng et al. creatively place surfactant monolayer at an air-liquid interface as a template to arrange monomers into an ordered pattern, the reaction initiated at the order monomers, resulting in highly crystalline COF films. Through the surfactant-monolayer-assisted interfacial synthesis (SMAIS) strategy, a highly crystalline film with controllable domain size and thickness can be obtained.⁶⁵ This gas-liquid interface synthesis method (SMAIS) has received widespread attention and is used to synthesize COF films with different structures and in different electronic devices.^{63,64,66} Zheng et al. employed sacrificial small-molecule structure-directing agents to orchestrate the interdigitation of adjacent crystalline polymer chains across grain boundaries, constructing a novel intercrystalline architecture—the woven grain boundary. Among their notable achievements, this is particularly worth highlighting. This ingenious woven grain boundary motif endowed the fully crystalline 2D COF films with exceptional mechanical robustness, toughness, and elasticity, which holds profound implications for the implementation of COFs in flexible device applications.⁶⁸ In addition to the template methods, the systems with highly reversible linkers, crystalline films could be synthesized

without templates at both liquid-liquid interfaces and gas-liquid interfaces. For example, Banerjee et al. prepared highly crystalline COF films with a controllable thickness of 50–200 nm, which also demonstrates its certain universality.⁶⁰ Importantly, at the dual-solvent gas-liquid interface, the preparation of COF films with controllable thicknesses of 2–150 nm can be achieved at the wafer level by limiting the reaction area.⁶²

2.5 | Electrochemical methods

Electrochemical techniques have recently emerged as a promising approach for the synthesis of COFs, offering advantages such as milder reaction conditions, shorter reaction times, and better control over film thickness and morphology.⁶⁹

One in situ electropolymerization strategy reported by Nejati et al. involves the coupling reactions of the oxidized para-aminophenyl substituents of 5,10,15,20-tetrakis(4-aminophenyl)porphyrin (TAPP) monomers on the electrode surface.⁶⁹ This process forms phenazine-linked COF films directly on the electrode, exhibiting good crystallinity and tunable thickness. Zhang et al. demonstrated the possibility of simultaneous polymerization and controllable film fabrication of C-C linked COF at the cathode surface through electrochemical dehalogenation under neutral and mild conditions.^{71,72}

2.6 | Other methods

Additional approaches to fabricating high-quality COF films include chemical vapor deposition techniques,^{73,74} as well as solid-state reactions between monomers or COF precursors together with catalysts coated on the surface glass slide in a sealed system.^{75,76}

3 | COFs FOR DIVERSE FLEXIBLE ELECTRONIC DEVICES

In the rapidly evolving field of flexible electronic devices, COFs have emerged as a pivotal material due to their unique structural versatility and tunable properties. This section delves into the integration of COFs into the realm of flexible electronics, highlighting their potential to enhance device performance and flexibility. We will explore various applications of COF-based materials in different devices, including energy storage devices, sensors and memristors, underscoring the advancements and challenges in this area. The discussion aims to provide a comprehensive overview of current achievements

and the promising future of COFs in improving the functionality and adaptability of electronic devices.

3.1 | Energy storage devices

Energy storage devices play a very important role in the development of modern flexible wearable devices.⁷⁷ Therefore, the development of energy storage devices with a long cycle life and excellent energy density has become one of the major challenges.⁷⁸ The application of COFs in flexible energy storage devices mainly focuses on solid-state lithium-ion batteries and supercapacitors.

3.1.1 | Batteries

COF is widely used as a solid state electrolyte (SSE) in solid-state batteries. Xu et al. prepared flexible COF SSE films with high electrical conductivity and excellent mechanical strength.³⁹ The COF contained electron-withdrawing triazine and polyfluorophenyl groups. This COF SSE had good mechanical properties and could significantly inhibit the growth of lithium dendrites. The solid-state pouch cell based on this COF can work efficiently even in the fully folded state. Manthiram et al. loaded the novel electrolyte DMA@LiTFSI into LiCOF pores for in situ polymerization.³⁸ The COF-SOH was prepared via a Schiff-based condensation reaction between 1,3,5-tricarbonylresorcinol and 1,4-phenylenediamine-2-sulfonic acid. Then, the COF-SOH was lithiated to obtain LiCOF (Figure 1B). The as-synthesized DMA@LiTSFL-mediated COF electrolyte (DLC) compensated for the defects of traditional solid polymer electrolyte (SPE) and the original LiCOF transport mode, which effectively improved the conductivity of Li⁺ (Figure 1A). Significantly, it could be fabricated into ultra-thin films with high flexibility. This novel SSE was used in the assembly of the foldable solid-state flexible pouch cells. Compared to LiCOF electrolyte, the DLC electrolyte allowed for stable lithium plating/stripping (0.3 mA cm⁻²) in Li|SSE|Li symmetric batteries for a duration of 450 h (Figure 1C). As a flexible pouch battery, this battery could remain operational in various folded states, even in a fully folded state (Figure 1D). The direct casting of the precursor of the DLC paste onto the cathode surface ensured uniform contact between the electrolyte and the electrode (Figure 1E). After a series of bending tests, the final performance of the battery was virtually unaffected, delivering a capacity of 120 mAh g⁻¹ at a rate of 0.1 C after 80 cycles (Figure 1F).

The above COF-based electrolytes achieved good electrical conductivity through electrolytes encapsulated

in the pores of the COF. Researchers have also investigated the direct modification of the COF by introducing ion-conducting chemical groups to prepare COF conductors. Huang et al. prepared a COF with multi-cationic molecular chains (COF-MCMCs) solid-state electrolyte for selective and efficient ion transport (Figure 2A).³⁷ In this electrolyte, the multication molecular chains formed an ion transport network that acted as cation-selective gates. Li⁺ could move rapidly through the channels, while anion migration was paralyzed by Coulombic interactions. Then a solid-state battery was initially assembled to test the electrochemical performance of the COF-MCMC electrolyte. It exhibited excellent multiplicative performance with more than 100 cycles at 0.2 C without obvious capacity loss. In addition, a flexible pouch cell with a limited lithium source (50 μm Li/Cu foil) was fabricated, and it could be successfully performed for 50 cycles at 0.1 C (Figure 2B). Remarkably, this flexible pouch cell could continue to work after bending, rolling, or cutting to power the light panel (insets of Figure 2B).

In addition to their application in solid-state lithium-ion batteries, COFs were also employed as a protective layer in aqueous zinc-ion batteries. Guo et al. attached FCOF to the surface of Zn to make the FCOF@Zn electrode.⁶⁷ The FCOF was synthesized with 2, 3, 5, 6-tetrafluoroterephthaldehyde and 1, 3, 5-tris (4-aminophenyl) benzene (Figure 2C). Strong interactions between fluorine and zinc in FCOF reduced the surface energy of zinc, thus inhibiting the growth of dendrite. Moreover, the fluorine-containing nano-channels could promote ion transfer and prevent electrolyte penetration, thus improving corrosion resistance. In this research, a flexible transparent battery with MnO₂ cathodes and FCOF@Zn anodes on flexible PVC substrates was assembled (Figure 2D). The FCOF film on the surface of Zn foil was tight enough even when the Zn foil was rolled and bent (Figure 2E). In terms of practical applications, the flexible battery could be used in wearable bracelets to light up light-emitting diode (LED) indicators (Figure 2F). The cycling performance of the flexible cell under different bending conditions was tested (Figure 5G-I). The charging and discharging curves remained almost unchanged at bending angles of 0°, 45°, and 60°, respectively (insets of Figure 5H,I). It indicated that the flexible battery had excellent performance with good mechanical stability and flexibility for practical applications.

3.1.2 | Supercapacitor

There are two mechanisms for supercapacitors: electrochemical double-layer capacitance (EDLC) and

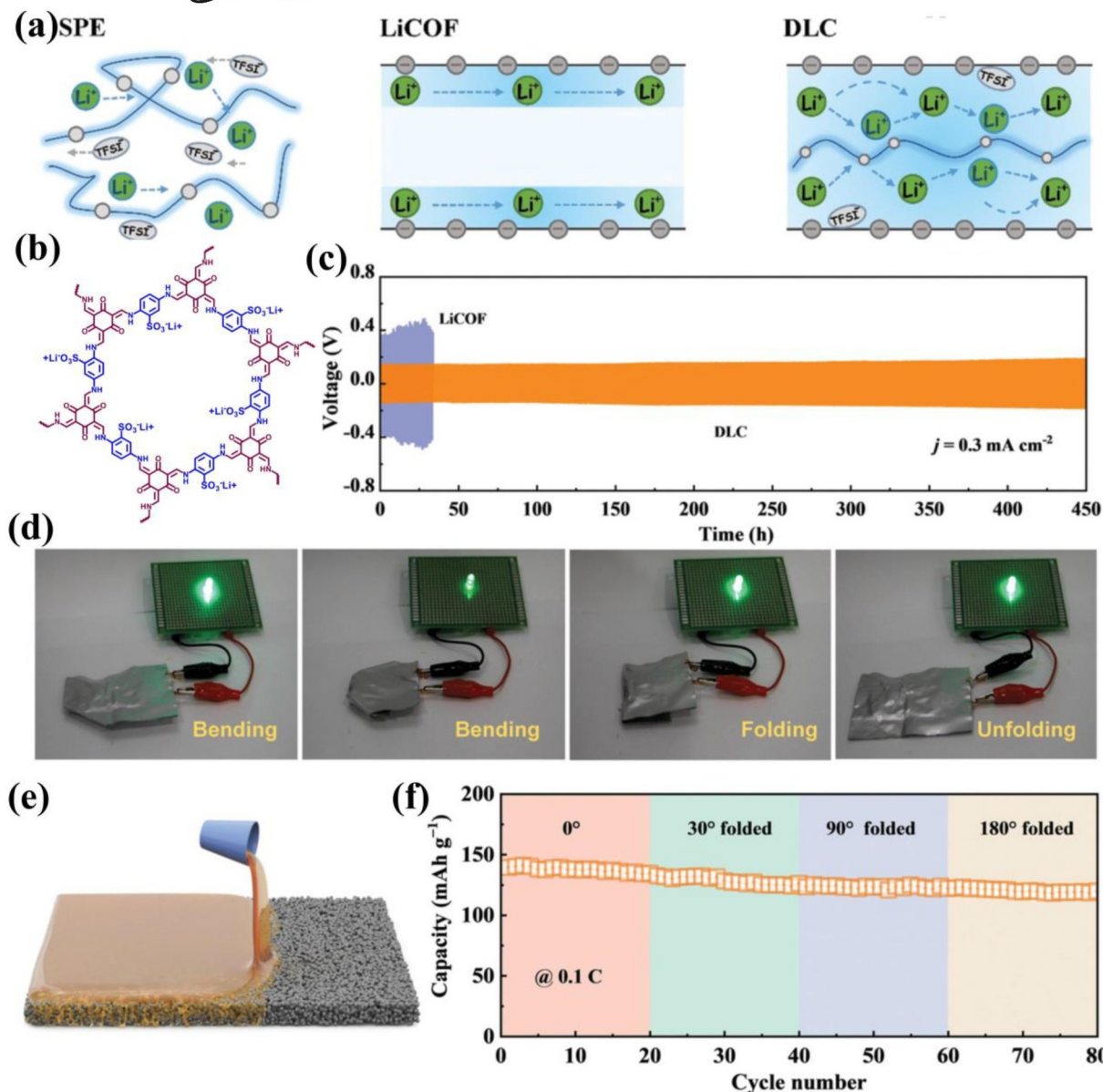


FIGURE 1 (A) Schematic of the Li⁺ transport mechanisms in conventional SPE, LiCOF, and DLC. (B) Chemical structure of LiCOF. (C) Cycling Performance of LiI|SSE|Li Symmetric Batteries. (D) Digital photos of flexible Li|DLC|LFP pouch batteries work under different bending conditions. (E) Schematic of an integrated DLC cathode structure prepared by a scalable tape casting method. (F) Cycling performance of flexible Li|DLC|LFP pouch batteries under different bending states. Reproduced with permission.³⁸ Copyright 2022, Wiley-VCH.

pseudocapitance (PC).^{79–82} COFs can realize high EDLC and high PC as the electrodes of supercapacitors.^{83,84} The π - π stacking as well as the high SSA of COFs can provide EDLC. Meanwhile, the abundant redox active sites on COFs can provide PCs. In addition, lightweight electrodes are crucial for the development of flexible supercapacitors (FSCs). COFs, as organic materials, can fulfill this point very easily. In 2018, Banerjee et al. realized the development potential of COFs in the FSC field. Then, the first COF-based self-standing FSC was prepared.⁷⁵ In this work, anthraquinone and

anthracene were selected to prepare solid-state symmetric COF as electrodes in FSCs. Due to the poor conductivity of COFs, some common conductive materials, including MXene, graphene and polypyrrole (Ppy), were generally introduced to improve their conductivity.^{41,42,45–47,49,50,52,85} Dong et al. prepared a COF/MXene membrane electrode through a self-assembly process.^{49,50} FSCs based on this electrode showed no significant change in CV curves under multiple bending conditions. Bending or twisting the device while supplying power to LEDs did not affect the current accordingly. This

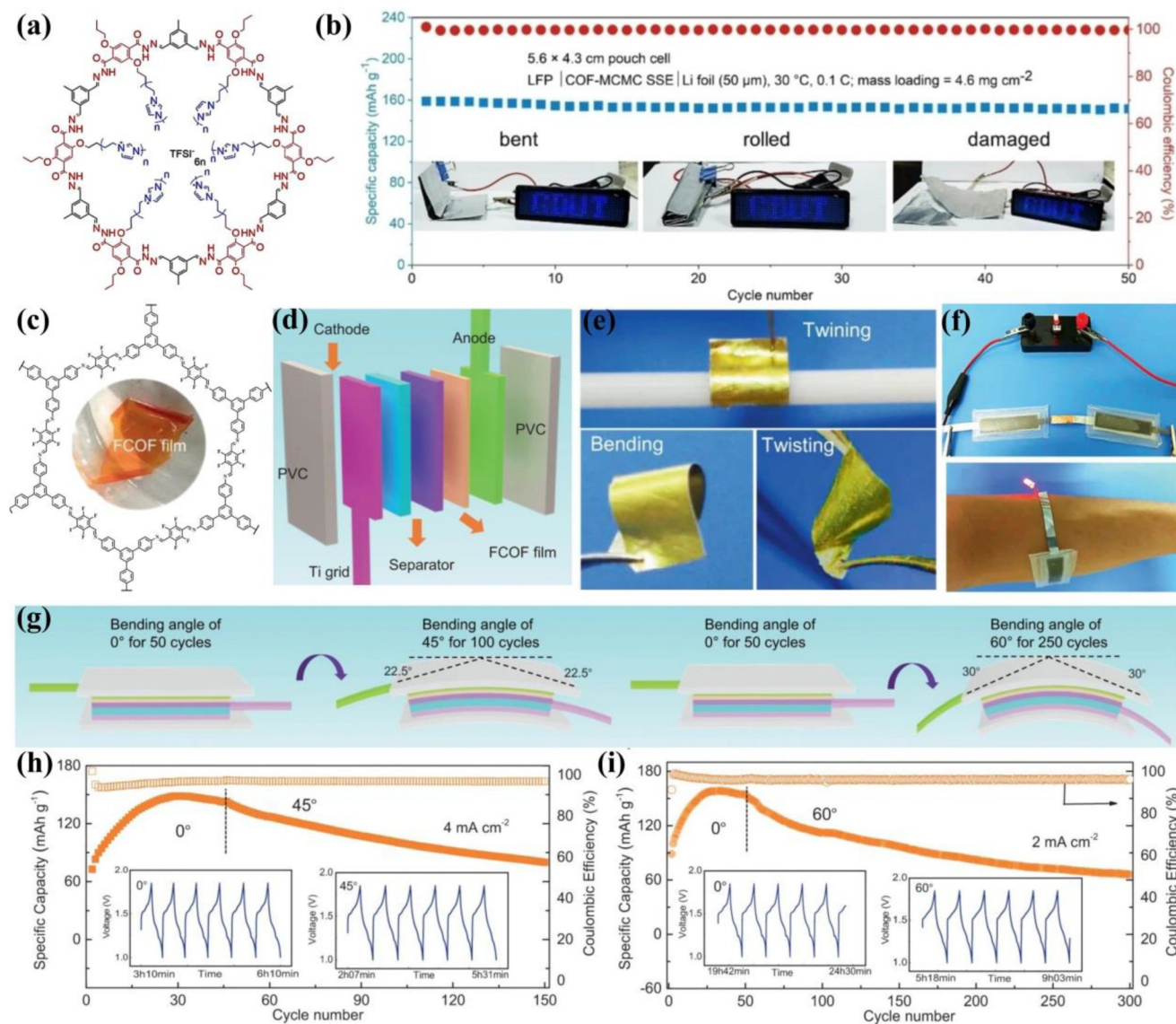


FIGURE 2 (A) Chemical structure of COF-MCMC. (B) Cycling performance of LFP|COF-MCMC SSE|Li pouch battery. The insets show that the pouch battery is capable of working after being bent, folded or cut. Reproduced with permission.³⁷ Copyright 2023, Wiley-VCH. (C) Chemical structure of FCOF and digital photographs of FCOF film. (D) Schematic structure of the flexible transparent aqueous zinc ion battery. (E) Digital photographs of FCOF@Zn in bending state. (F) A digital photograph of the battery powering an LED on a wearable device. (G–I) Cycling performance of flexible transparent batteries in different bending states. The insets are selected voltage-time profiles. Reproduced under terms of the CC-BY license.⁶⁷ Copyright 2021, Springer Nature.

demonstrated the excellent flexibility of the device for promising practical applications. Besides, the self-healing FSCs assembled by Lv et al. based on COF composites and novel ion-gel electrolyte were impressive. In this research, rGO was used to prepare a DaTp-COF/rGO hybrid electrode.⁸⁶ More importantly, a novel self-healing ion-gel electrolyte (P₂₈/Zn²⁺/2IL) was developed, providing the foundation for the mechanical stability and self-healing ability of the FSC (Figure 3A). This kind of electrolyte was tightly attached to the COF/rGO electrode to steadily assemble the FSCs. The hybrid electrode did not separate or peel off, even if the device was bent or

folded. The stability was also confirmed by CV curves due to the negligible change during the bending process (Figure 3B). The capacitance retention of the FSC could reach as low as 95% during bending from 0 to 120°. Notably, FSCs also displayed excellent self-healing capabilities. After being cut in half and healed for 90 min without external intervention, the specific capacitance remained at 138 F/g (Figure 3C). In addition, during the healing process, the FSC could also continue to light up the LED bulb (Figure 3E).

In recent studies, COFs have also been used directly as electrodes for energy storage. Qiao et al. assembled

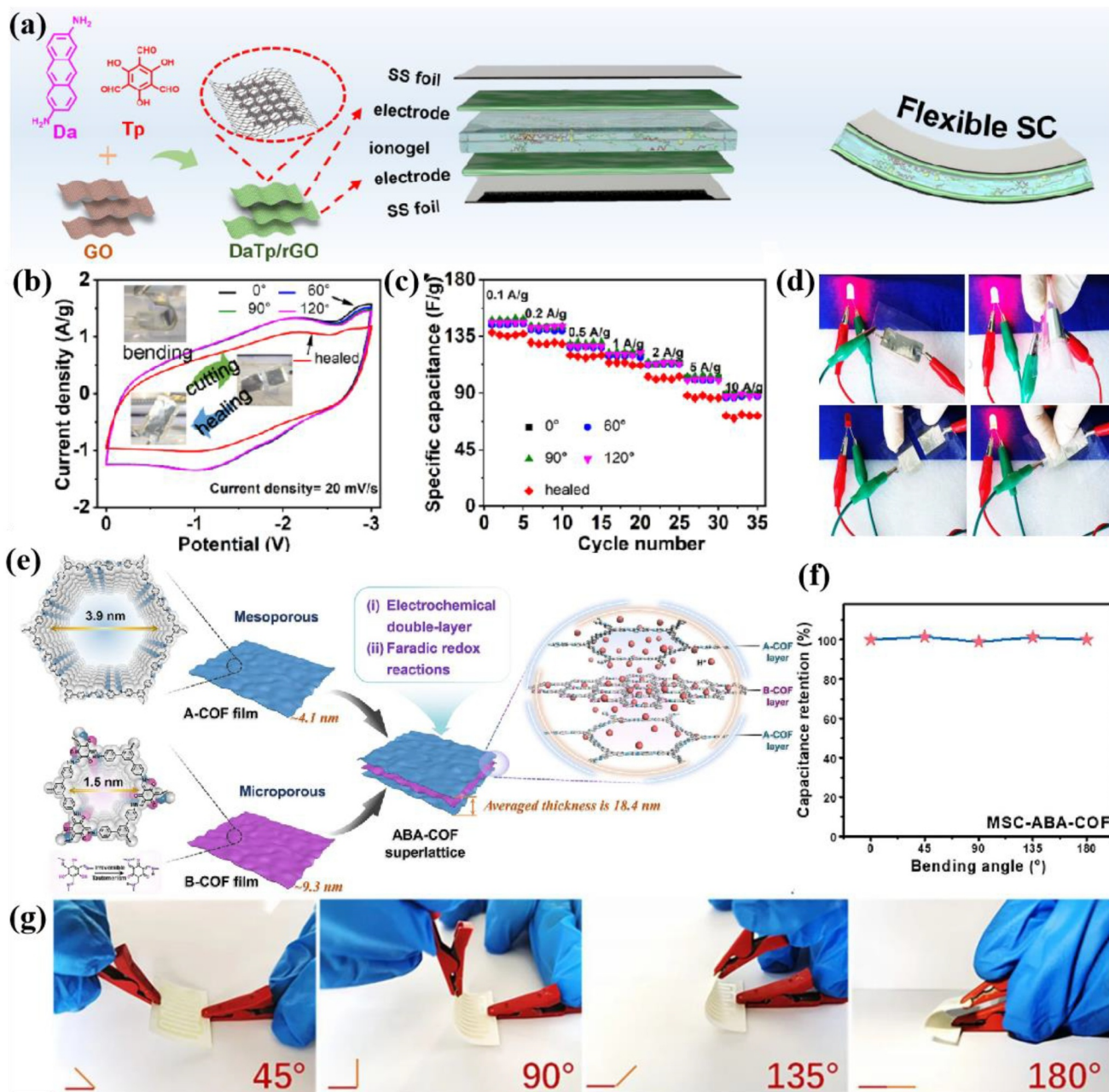


FIGURE 3 (A) Schematic of FSC assembled with $P_{28}/Zn^{2+}/2IL$ ionogel-electrolyte and DaTp/rGO electrodes. (B) CV curves of FSC in different bending states and after healing. The inserts are digital photographs of FSC. (C) Rate performance of FSCs in different bending states and after healing. (D) The FSC provides power to the bulb before cutting and bending as well as after cutting and self-healing. Reproduced with permission.⁸⁶ Copyright 2023, Elsevier. (E) Schematic structure of ABA-COF superlattice. (F) Capacitance retention of MSC-ABA-COF in different bending states. (G) Digital photographs of MSC-ABA-COF in different bending states. Reproduced with permission.⁶⁴ Copyright 2023, Springer Nature.

A-COF and B-COF through layer-by-layer transfer to obtain ABA-COF superlattice material with a “nano-hourglass” spatial configuration, accelerating dynamic charge transport/accumulation and promoting sufficient redox reactions due to EDLC and pseudo capacitance energy storage mechanisms (Figure 3F).⁶⁴ Flexible micro-supercapacitors, assembled with ABA-COF as fork-finger electrodes, demonstrated good bending

resistance. There was no significant difference in the frontal capacitance values at different bending degrees from 0 to 180° (Figure 3G). Besides, the capacitance retention rate was up to 83.9% after 8000 charge/discharge cycles, showing good cycling stability.

COFs offer high surface area and tunable porosity, enhancing the performance of flexible batteries and supercapacitors. Their structural versatility allows for

improved energy density, cycle stability, and mechanical flexibility, making them ideal for next-generation portable and wearable electronics.

3.2 | Memristor

A memristor is a nonlinear dynamic electronic device with a memory effect that can change its resistance value in response to external stimulation and maintain that state, with potential for applications in areas such as memory and neuron simulation.^{87–93} Meanwhile, the active sites and pore environment of COFs can be altered by monomer selection and post-modification. In this way, the ionic conductivity required for memristor materials can be generated. COFs can provide good platforms for the development of new-generation memory devices. Thus, COFs have attracted widespread attention in the field of memristors in recent years.

Liu et al. used an interfacial method to prepare 2DP_{BTA + PDA} films for a nonvolatile resistive memristor device via the Schiff base condensation reaction between benzene-1,3,5-tricarbaldehyde (BTA) and p-phenylenediamine (PDA) (Figure 4A).⁶² This is the first time that 2D COFs were used to prepare memristors. The intrinsic porosity, coordination ability of the imine groups, and high uniformity of this 2DP_{BTA + PDA} film

made it an ideal resistive switching dielectric layer for electrochemical metallization memories. The prepared Ag/2DP_{BTA + PDA}/ITO devices demonstrated stable memory behaviors, showing high on/off current ratios over 1.0×10^5 s after 200 cycles (Figure 4B). Besides, the data retention capability extended up to 3.5×10^4 s (Figure 4C). More notably, based on the thermal stability of the 2DP_{BTA + PDA} film, the device remained reliable after heating at 300°C (Figure 4D). Moreover, the inherent flexibility and uniformity of the 2DP_{BTA + PDA} film allowed it to be applied to flexible memory devices. The flexible device remained high performance after 500 bending cycles (Figure 4E). These indicated that the amnesia had good mechanical stability and reliability.

COFs-based flexible memristors exhibit excellent switching behavior, high endurance, and low power consumption. Their customizable architecture and superior flexibility enable advanced data storage and neuro-morphic computing applications, paving the way for innovative, flexible electronic circuits and devices.

3.3 | Humidity sensor

Chemical sensors are a class of devices or materials capable of detecting and measuring the presence or concentration changes of specific chemicals (target molecules).^{35,94} It is

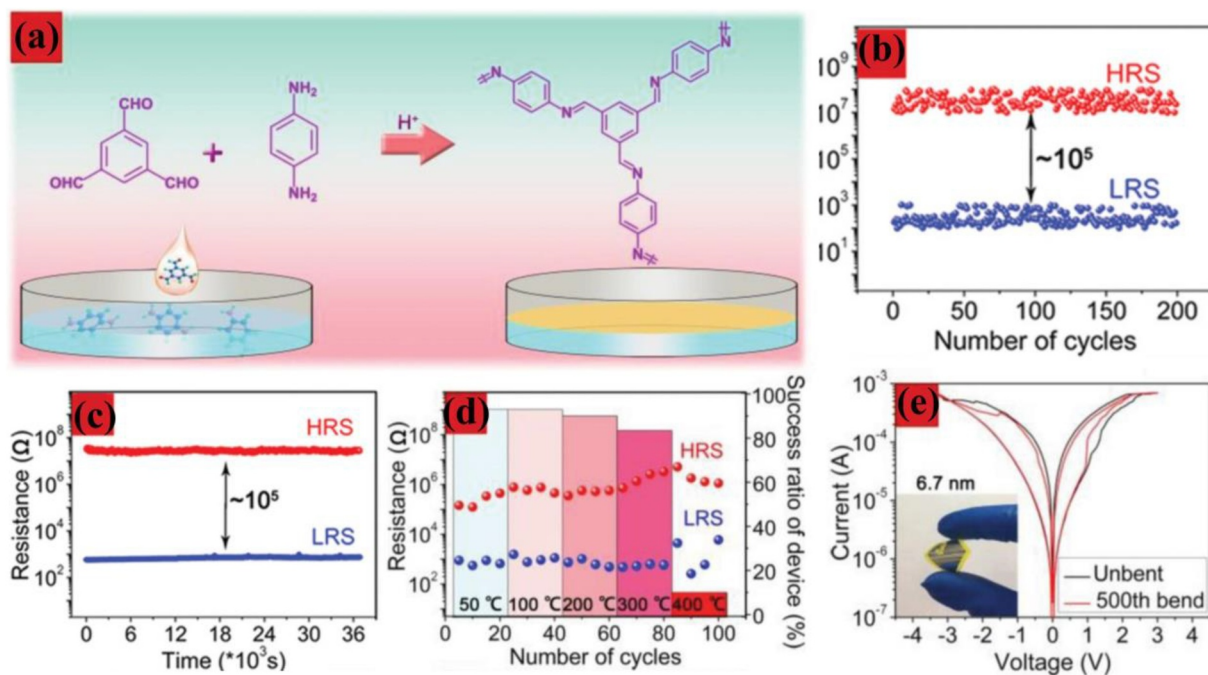


FIGURE 4 (A) Schematic of synthesized 2DP_{BTA + PDA} films. (B) Plot of endurance performance of on/off resistors as a function of the number of cycles. (C) The retention time of the device in the “on” and “off” states. (D) “On” and “off” status and success rate of Ag/2DP_{BTA + PDA}/ITO devices measured over the 50°C–400°C temperature range. (E) Switching curves of flexible Ag/2DP_{BTA + PDA}/graphene devices before and after 500 cycles of repeated mechanical bending. Reproduced with permission.⁶² Copyright 2019, WILEY-VCH.

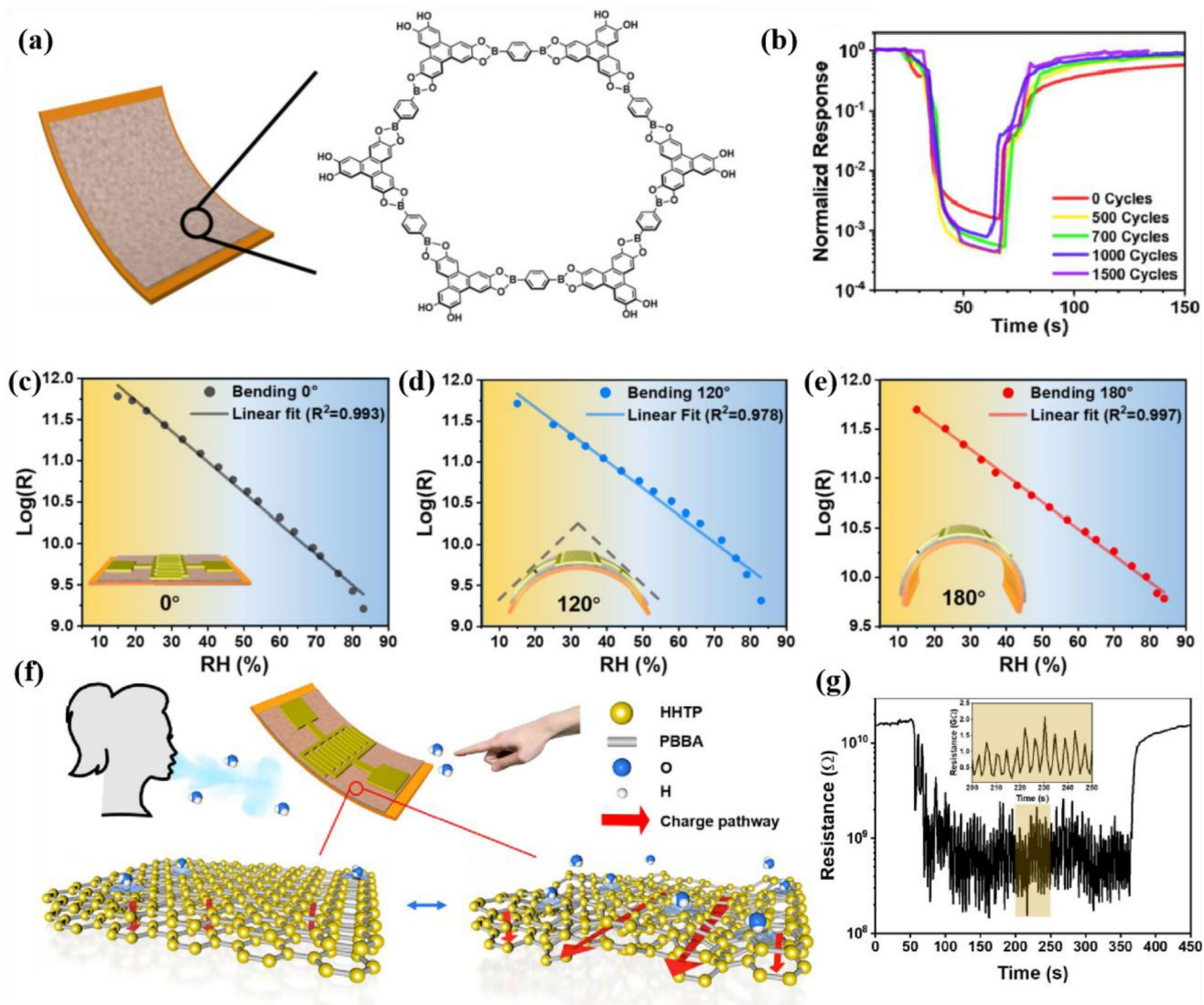


FIGURE 5 (A) Schematic of COF-5 film on PI substrate and structure of COF-5. (B) RH humidity test of the sensor after different bending cycles at 180°. (C–E) Bending test of the humidity sensor at bending angles of 0°, 120° and 180°. (F) Schematic of the sensing mechanism for practical applications. (G) The breathing signal monitored by the sensor on the mask. Reproduced with permission.⁷⁶ Copyright 2023, Wiley-VCH.

important for applications in environmental monitoring, biomedicine, food safety and other fields. Excellent chemical sensors require active materials with a large SSA, a fast sensing response and abundant reaction sites.³⁴ The large SSA and abundant active sites of two-dimensional COFs can provide substantial areas for sensing process, significantly improving the monitoring performance of the sensors. COFs can integrate specific chemical acceptors that could react with target molecules, thus inducing changes in electrical signals.^{95–98} Therefore, COFs have received extensive attention in the field of flexible sensors.

Mei et al. prepared COF-5 thin films with superior hydrophilicity for assembling flexible humidity sensors (Figure 5A).⁷⁶ The COF-5 film was synthesized by a steam-assisted conversion method. First, a solvent containing the

monomer was dripped onto the polyimide film. Then, the polyimide film was placed in a sealed box to evaporate to form the film. The judicious design stems from the adsorption-desorption between water molecules and COF-5 since it could lead to reversible deformation of the COF layer and generate new conductive paths through π - π stacking. The sensor exhibited good repeatability and reversibility, with a response of 26 s and recovering time of 16 s, respectively. Besides, the corresponding curves of sensing after 500 and even up to 1500 bending cycles were basically the same, along with the performance at different bending states, indicating good bending endurance (Figure 5B–E). The humidity response of the sensor in the bending state was basically the same as that in the normal state with 50% relative humidity. Notably, the bent sensor

maintained a linear response to humidity at different bending angles, with an R_2 value of more than 0.978. The excellent stability and sensitivity made COF-5 an ideal candidate for flexible sensors in practical situations. A medical mask to monitor breath rate was fabricated based on COF-5 (Figure 5F). The sensor accurately recorded respiratory signals over the course of 5 min of the test (Figure 5G). This research opens up new possibilities for flexible wearable devices in the monitoring of human life and health.

COFs provide excellent sensitivity, selectivity, and mechanical resilience in flexible sensors. Their tunable chemical functionalities and robust frameworks enhance the detection of gases, biomolecules, and environmental changes, making them crucial for flexible, wearable, and real-time monitoring technologies.

4 | SUMMARY AND OUTLOOK

In this review, the synthesis of COFs and their applications in flexible electronic devices have been summarized, including energy storage, data storage and sensing. Despite the impressive advances in COFs for flexible electronics, numbers of research in various domains remain limited. There is a clear need for further exploration to expand the utility of COFs in this rapidly evolving field.

COFs exhibit significant potential in flexible electronics due to their distinct porous structure, high surface area, crystallinity, and numerous reactive sites. Although COFs inherently exhibit low conductivity, their physicochemical properties can be enhanced through various strategies. For flexible energy storage devices, the high surface area and active sites of COFs can potentially increase the specific capacity of electrode materials, offering a novel approach for developing high-energy-density batteries and supercapacitors. Presently, using additives such as conductive polymers, carbon nanotubes, and other conductive materials for COFs composites through physical mixing can improve overall conductivity and optimize pore structure and active site distribution, thus balancing high energy and power densities. Future work could delve into COF through chemical modifications for energy storage applications.

COFs have also garnered interest in data storage, where their ion transport and redox behavior could enable low-power, high-density, nonvolatile memory. Furthermore, COFs with unique structures could exhibit dielectric properties, opening new avenues for storage unit construction. In photodetectors, the semiconducting nature and π -electron systems of COFs could offer

photoactivity. By fine-tuning their structure and pore environment, COFs could also be applied to solar cells and photodetection.^{99,100}

In sensor technology, COFs can be functionalized with specific groups to recognize particular molecules or ions, and their porous nature can concentrate guest molecules. Current research on COF-based sensors primarily investigates interactions with small molecules. However, the solubility and processability of traditionally synthesized COF powders are limited, hindering their application in wearable flexible devices. The development of COFs with good solubility and processability can contribute to the development of COFs for sensor applications.

Despite the promising applications of COFs in flexible electronics, the integration of COFs in devices still faces challenges, including the poor solubility and processability. Developing thin-film COFs that can grow orderly on substrates and align with existing integrated circuits processes is crucial. Moreover, enhancing the conductivity without compromising the structure and porosity of COF is a significant hurdle. Designing new conductive COFs is a vital future direction. Additionally, it is necessary to explore the physicochemical properties and application potential of COFs to provide a theoretical basis for their use in novel devices, such as photovoltaic conversion and energy transfer. For example, photoelectric conversion, energy transfer, and ion transport. In addition, integrating flexible COF devices is a major challenge. COFs need to be efficiently integrated into flexible substrates while maintaining device stretchability and flexibility. Therefore, advances in material design, interface engineering, and integration methods are necessary.

In short, COF-based flexible electronic devices represent an exciting frontier with rich scientific challenges and vast application potential. With sustainable research efforts and cross-disciplinary collaboration, we anticipate groundbreaking innovations in COF-based flexible electronics.

AUTHOR CONTRIBUTIONS

Jinghang Wu: Investigation; formal analysis; data curation; methodology; writing - original draft. **Shiwei Zhang:** Methodology; data curation; formal analysis; writing - original draft. **Qianfeng Gu:** Data curation; methodology; investigation; writing - original draft. **Qichun Zhang:** Conceptualization; formal analysis; supervision; funding acquisition; writing - review & editing.

ACKNOWLEDGMENTS

Q. Z. acknowledges the funding support from the City University of Hong Kong (9380117 and 7020089) and

from the Innovation and Technology Fund (ITF, ITS/322/22), Hong Kong, P. R. China. Q.Z. also thanks the funding support from State Key Laboratory of Supramolecular Structure and Materials, Jilin University (sklssm2024039), P. R. China.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interests.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

ORCID

Qianfeng Gu  <https://orcid.org/0000-0003-1854-8659>

REFERENCES

- D. Zhong, C. Wu, Y. Jiang, Y. Yuan, M. Kim, Y. Nishio, C.C. Shih, W. Wang, J.-C. Lai, X. Ji, T. Z. Gao, Y.-X. Wang, C. Xu, Y. Zheng, Z. Yu, H. Gong, N. Matsuhisa, C. Zhao, Y. Lei, D. Liu, S. Zhang, Y. Ochiai, S. Liu, S. Wei, J. B.-H. Tok, Z. Bao, *Nature* **2024**, 627, 313.
- H.-C. Wu, S. Nikzad, C. Zhu, H. Yan, Y. Li, W. Niu, J. R. Matthews, J. Xu, N. Matsuhisa, P. K. Arunachala, R. Rastak, C. Linder, Y.-Q. Zheng, M. F. Toney, M. He, Z. Bao, *Nat. Commun.* **2023**, 14, 8382.
- C. Wu, D. Zhong, W. Wang, Y. Jiang, Y. Nishio, Y. Yuan, Q. Liu, J. B.-H. Tok, Z. Bao, *IEEE Trans. Electron Devices* **2024**, 71(5), 3411.
- Y. Li, C. Zhang, Z. Shi, C. Ma, J. Wang, Q. Zhang, *Science Mater. China* **2021**, 65, 2110.
- Q. Zhang, *Front. Phys.* **2021**, 16, 13602.
- C. Ding, Y. Wang, C. Li, J. Wang, Q. Zhang, W. Huang, *Chem. Sci.* **2024**, 15, 4952.
- W. Wang, Y. Jiang, D. Zhong, Z. Zhang, S. Choudhury, J.-C. Lai, H. Gong, S. Niu, X. Yan, Y. Zheng, C.-C. Shih, R. Ning, Q. Lin, D. Li, Y.-H. Kim, J. Kim, Y.-X. Wang, C. Zhao, C. Xu, X. Ji, Y. Nishio, H. Lyu, J. B.-H. Tok, Z. Bao, *Science* **2023**, 380(6646), 735.
- B. Dai, C. Gao, Y. Xie, *VIEW* **2022**, 3(5), 20220027.
- S. Nie, N. Hao, K. Zhang, C. Xing, S. Wang, *Cellulose* **2020**, 27, 4173.
- B. Zhang, J. Li, J. Zhou, L. Chow, G. Zhao, Y. Huang, Z. Ma, Q. Zhang, Y. Yang, C. K. Yiu, J. Li, F. Chun, X. Huang, Y. Gao, P. Wu, S. Jia, H. Li, D. Li, Y. Liu, K. Yao, R. Shi, Z. Chen, B. L. Khoo, W. Yang, F. Wang, Z. Zheng, Z. Wang, X. Yu, *Nature* **2024**, 628, 84.
- Y. Zheng, L. Michalek, Q. Liu, Y. Wu, H. Kim, P. Sayavong, W. Yu, D. Zhong, C. Zhao, Z. Yu, J. A. Chiong, H. Gong, X. Ji, D. Liu, S. Zhang, N. Prine, Z. Zhang, W. Wang, J. B.-H. Tok, X. Gu, Y. Cui, J. Kang, Z. Bao, *Nat. Nanotechnol.* **2023**, 18, 1175.
- C. B. Cooper, S. E. Root, L. Michalek, S. Wu, J.-C. Lai, M. Khatib, S. T. Oyakhire, R. Zhao, J. Qin, Z. Bao, *Science* **2023**, 380(6648), 935.
- C. Liao, M. Zhang, M. Y. Yao, T. Hua, L. Li, F. Yan, *Adv. Mater.* **2015**, 27(46), 7493.
- S. Yuan, K. Ding, X. Zeng, D. Bin, Y. Zhang, P. Dong, Y. Wang, *Adv. Mater.* **2023**, 35(13), 2206228.
- B.-X. Mi, P.-F. Wang, M.-W. Liu, H.-L. Kwong, N.-B. Wong, C.-S. Lee, S.-T. Lee, *Chem. Mater.* **2003**, 15(16), 3148.
- K. Geng, T. He, R. Liu, S. Dalapati, K. T. Tan, Z. Li, S. Tao, Y. Gong, Q. Jiang, D. Jiang, *Chem. Rev.* **2020**, 120(16), 8814.
- Q. Gu, X. Lu, C. Chen, R. Hu, X. Wang, G. Sun, F. KANG, J. Yang, X. Wang, J. Wu, Y. Y. Li, Y.-K. Peng, W. Qin, Y. Han, X. Liu, Q. Zhang, *ACS Nano* **2023**, 17(23), 23903.
- Z. Wang, S. Zhang, Y. Chen, Z. Zhang, S. Ma, *Chem. Soc. Rev.* **2020**, 49, 708.
- X. Liu, D. Huang, C. Lai, G. Zeng, L. Qin, H. Wang, H. Yi, B. Li, S. Liu, M. Zhang, R. Deng, Y. Fu, L. Li, W. Xue, S. Chen, *Chem. Soc. Rev.* **2019**, 48, 5266.
- F. Kang, X. Wang, C. Chen, C.-S. Lee, Y. Han, Q. Zhang, *J. Am. Chem. Soc.* **2023**, 145(28), 15465.
- S. Zhang, X. Wang, F. Kang, Q. Gu, G. Sun, Y.-K. Peng, Q. Zhang, *SmartMat* **2024**, e1265.
- N. Keller, T. Bein, *Chem. Soc. Rev.* **2021**, 50, 1813.
- M. Lu, M. Zhang, J. Liu, Y. Chen, J.-P. Liao, M.-Y. Yang, Y.-P. Cai, S.-L. Li, Y.-Q. Lan, *Angew. Chem. Int. Ed.* **2022**, 61(15), e202200003.
- C. R. DeBlase, K. E. Silberstein, T.-T. Truong, H. D. Abruña, W. R. Dichtel, *J. Am. Chem. Soc.* **2013**, 135(45), 16821.
- J. Lv, Y.-X. Tan, J. Xie, R. Yang, M. Yu, S. Sun, M.-D. Li, D. Yuan, Y. Wang, *Angew. Chem. Int. Ed.* **2018**, 57(39), 12716.
- Z. Yang, J. Liu, Y. Li, G. Zhang, G. Xing, L. Chen, *Angew. Chem. Int. Ed.* **2021**, 60(38), 20754.
- J. Sun, F. Kang, D. Yan, T. Ding, Y. Wang, X. Zhou, Q. Zhang, *Angew. Chem. Int. Ed.* **2024**, 63, e202406511.
- J. Sun, Y. Fei, H. Tang, J. Bao, Q. Zhang, X. Zhou, *ACS Appl. Energy Mater.* **2023**.
- J. Sun, Y. Xu, Y. Lv, Q. Zhang, X. Zhou, *CCS Chem.* **2023**, 5(6), 1259.
- Y. Shi, J. Yang, F. Gao, Q. Zhang, *ACS Nano* **2023**, 17(3), 1879.
- S. Xu, Q. Zhang, *Mater. Today Energy* **2021**, 20, 100635.
- M. Liu, Y.-J. Chen, X. Huang, L.-Z. Dong, M. Lu, C. Guo, D. Yuan, Y. Chen, G. Xu, S.-L. Li, Y.-Q. Lan, *Angew. Chem. Int. Ed.* **2022**, 61(12), e202115308.
- A. M. Evans, N. P. Bradshaw, B. Litchfield, M. J. Strauss, B. Seckman, M. R. Ryder, I. Castano, C. Gilmore, N. C. Gianeschi, C. R. Mulzer, M. C. Hersam, W. R. Dichtel, *Adv. Mater.* **2020**, 32(42), 2004205.
- W. Wang, W. Zhao, H. Xu, S. Liu, W. Huang, Q. Zhao, *Coord. Chem. Rev.* **2021**, 429, 213616.
- A. Mei, Z. Yang, M. Zhou, W. Jin, Y. Liu, W. Chen, *Analysis Sensing* **2024**, 4(3), e202300078.
- X. Zhao, P. Pachfule, A. Thomas, *Chem. Soc. Rev.* **2021**, 50, 6871.
- W. Gong, Y. Ouyang, S. Guo, Y. Xiao, Q. Zeng, D. Li, Y. Xie, Q. Zhang, S. Huang, *Angew. Chem. Int. Ed.* **2023**, 62(25), e202302505.
- D. Guo, D. B. Shinde, W. Shin, E. Abou-Hamad, A. Emwas, Z. Lai, A. Manthiram, *Adv. Mater.* **2022**, 34(23), 2201410.
- C. Niu, W. Luo, C. Dai, C. Yu, Y. Xu, *Angew. Chem. Int. Ed.* **2021**, 60(47), 24915.
- Y. Yang, K. Börjesson, *Trechm* **2022**, 4(1), 60.
- M. Yao, C. Guo, Q. Geng, Y. Zhang, X. Zhao, X. Zhao, Y. Wang, *Ind. Eng. Chem. Res.* **2022**, 61(22), 7480.

42. W. Chen, P. Xiao, H. Chen, H. Zhang, Q. Zhang, Y. Chen, *Adv. Mater.* **2019**, *31*(9), 1802403.
43. B.-Q. Li, S.-Y. Zhang, B. Wang, Z.-J. Xia, C. Tang, Q. Zhang, *Energy Environ. Sci.* **2018**, *11*, 1723.
44. J. Xu, Y. He, S. Bi, M. Wang, P. Yang, D. Wu, J. Wang, F. Zhang, *Angew. Chem. Int. Ed.* **2019**, *58*(35), 12065.
45. Y. Dong, Y. Wang, X. Zhang, Q. Lai, Y. Yang, *Chem. Eng. J.* **2022**, *449*, 137858.
46. X. Fan, Y. Zhou, X. Jin, R.-B. Song, Z. Li, Q. Zhang, *Carbon Energy* **2021**, *3*(3), 449.
47. Y. Zhang, Q. Zhang, G. Chen, *Carbon Energy* **2020**, *2*(3), 408.
48. X. Kong, S. Zhou, M. Stromme, C. Xu, *Carbon* **2021**, *171*, 248.
49. N. An, Z. Guo, C. Guo, M. Wei, D. Sun, Y. He, W. Li, L. Zhou, Z. Hu, X. Dong, *Chem. Eng. J.* **2023**, *458*, 141434.
50. S. Ling, C. Zhang, C. Ma, Y. Li, Q. Zhang, *Adv. Funct. Mater.* **2022**, *33*(1), 2208320.
51. Z. Xu, Y. Liu, Z. Wu, R. Wang, Q. Wang, T. Li, J. Zhang, J. Cheng, Z. Yang, S. Chen, M. Miao, D. Zhang, *Chem. Eng. J.* **2020**, *387*, 124071.
52. S. Haldar, D. Rase, P. Shekhar, C. Jain, C. P. Vinod, E. Zhang, L. Shupletsov, S. Kaskel, R. Vaidhyanathan, *Adv. Energy Mater.* **2022**, *12*(34), 2200754.
53. W. Wang, W. Zhao, T. Chen, Y. Bai, H. Xu, M. Jiang, S. Liu, W. Huang, Q. Zhao, *Adv. Funct. Mater.* **2021**, *31*(29), 2010306.
54. M. Wang, P. Zhang, X. Liang, J. Zhao, Y. Liu, Y. Cao, H. Wang, Y. Chen, Z. Zhang, F. Pan, Z. Zhang, Z. Jiang, *Nat. Sustain.* **2022**, *5*, 518.
55. L. Wang, C. Zeng, H. Xu, P. Yin, D. Chen, J. Deng, M. Li, N. Zheng, C. Gu, Y. Ma, *Chem. Sci.* **2019**, *10*, 1023.
56. Q. Fu, T. Wang, Y. Sun, N. Zheng, Z. Xie, D. Lu, Z. Xu, X. Wan, Y. Zhang, Y. Liu, *Sci. China Chem.* **2021**, *64*, 82.
57. P. Peng, L. Shi, F. Huo, S. Zhang, C. Mi, Y. Cheng, Z. Xiang, *ACS Nano* **2019**, *13*(1), 878.
58. S. Jhulki, J. Kim, I.-C. Hwang, G. Haider, J. Park, J. Y. Park, Y. Lee, W. Hwang, A. A. Dar, B. Dhara, S. H. Lee, J. Kim, J. Y. Koo, M. H. Jo, C.-C. Hwang, Y. H. Jung, Y. Park, M. Kataria, Y.-F. Chen, S.-H. Jhi, M.-H. Baik, K. Baek, K. Kim, *Chem.* **2020**, *6*, 2035.
59. J. Guo, G. Meng, X. Zhang, H. Huang, J. Shi, B. Wang, X. Hu, J. Yuan, W. Ma, *Adv. Mater.* **2023**, *35*(38), 2302839.
60. K. Dey, M. Pal, K. C. Rout, S. Kunjattu H, A. Das, R. Mukherjee, U. K. Kharul, R. Banerjee, *J. Am. Chem. Soc.* **2017**, *139*(37), 13083.
61. J. Yang, B. Tu, G. Zhang, P. Liu, K. Hu, J. Wang, Z. Yan, Z. Huang, M. Fang, J. Hou, Q. Fang, X. Qiu, L. Li, Z. Tang, *Nat. Nanotechnol.* **2022**, *17*, 622.
62. J. Liu, F. Yang, L. Cao, B. Li, K. Yuan, S. Lei, W. Hu, *Adv. Mater.* **2019**, *31*(28), 1902264.
63. X. Xu, J. Zhang, Z. Zhang, G. Lu, W. Cao, N. Wang, Y. Xia, Q. Feng, S. Qiao, *Nano-Micro Lett.* **2024**, *16*, 116.
64. X. Xu, Z. Zhang, R. Xiong, G. Lu, J. Zhang, W. Ning, S. Hu, Q. Feng, S. Qiao, *Nano-Micro Lett.* **2023**, *15*, 25.
65. K. Liu, H. Qi, R. Dong, R. Shivhare, M. Addicoat, T. Zhang, H. Sahabudeen, T. Heine, S. Mannsfeld, U. Kaiser, Z. Zheng, X. Feng, *Nat. Chem.* **2019**, *11*, 994.
66. X. Xu, R. Xiong, Z. Zhang, X. Zhang, C. Gu, Z. Xu, S. Qiao, *Chem. Eng. J.* **2022**, *447*, 137447.
67. Z. Zhao, R. Wang, C. Peng, W. Chen, T. Wu, B. Hu, W. Weng, Y. Yao, J. Zeng, Z. Chen, P. Liu, Y. Liu, G. Li, J. Guo, H. Lu, Z. Guo, *Nat. Commun.* **2021**, *12*, 6606.
68. Y. Yang, B. Liang, J. Kreie, M. Hamsch, Z. Liang, C. Wang, S. Huang, X. Dong, L. Gong, C. Liang, D. Lou, Z. Zhou, J. Lu, Y. Yang, X. Zhuang, H. Qi, U. Kaiser, S. C. B. Mannsfeld, W. Liu, A. Götzhauser, Z. Zheng, *Nature* **2024**, *630*, 878.
69. E. Tavakoli, A. Kakekhani, S. Kaviani, P. Tan, M. M. Ghaleni, M. A. Zaeem, A. M. Rappe, S. Nejati, *J. Am. Chem. Soc.* **2019**, *141*(50), 19560.
70. X. Wang, P. She, Q. Zhang, *SmartMat* **2021**, *2*(3), 299.
71. X. Wang, J. Wu, H. Liu, F. Kang, F. Yan, Q. Zhang, *Macromolecules* **2023**, *56*(24), 10198.
72. X. Wang, L. Zhang, J. Wu, M. Xue, Q. Gu, J. Qi, F. Kang, Q. He, X. Zhong, Q. Zhang, *Small Methods* **2024**, 2400185.
73. M. Liu, Y. Liu, J. Dong, Y. Bai, W. Gao, S. Shang, X. Wang, J. Kuang, C. Du, Y. Zou, J. Chen, Y. Liu, *Nat. Commun.* **2022**, *13*, 1411.
74. N. Chaki Roy, T. Kundu, *RSC Adv.* **2023**, *13*, 3669.
75. A. Khayum M, V. Vijayakumar, S. Karak, S. Kandambeth, M. Bhadra, K. Suresh, N. Acharambath, S. Kurungot, R. Banerjee, *ACS Appl. Mater. Interfaces* **2018**, *10*(33), 28139.
76. A. Mei, W. Chen, Z. Yang, M. Zhou, W. Jin, S. Yang, K. Chen, Y. Liu, *Angew. Chem. Int. Ed.* **2023**, *62*(19), e202301440.
77. Z. Zeng, J. Shen, Y. Lai, G. Hua, Y. Wang, J. Liu, W. Tang, *Adv. Funct. Mater.* **2024**, 2401059.
78. J. He, L. Cao, J. Cui, G. Fu, R. Jiang, X. Xu, C. Guan, *Adv. Mater.* **2024**, *36*(4), 2306090.
79. J. Sun, B. Luo, H. Li, *Adv. Energy Sustainability Res.* **2022**, *3*(6), 2100191.
80. Y. Guo, K. Wang, Y. Hong, H. Wu, Q. Zhang, *Dalton Transactions* **2021**, *50*, 11331.
81. K. Wang, S. Wang, J. Liu, Y. Guo, F. Mao, H. Wu, Q. Zhang, *ACS Appl. Mater. Interface* **2021**, *13*(13), 15315.
82. C. Choi, D. S. Ashby, D. M. Butts, R. H. DeBlock, Q. Wei, J. Lau, B. Dunn, *Nat. Rev. Mater.* **2020**, *5*, 5.
83. S. Kandambeth, V. S. Kale, O. Shekhah, H. N. Alshareef, M. Eddaoudi, *Adv. Energy Mater.* **2022**, *12*(4), 2100177.
84. S. Xu, J. Wu, X. Wang, Q. Zhang, *Chem. Sci.* **2023**, *14*, 13601.
85. Y. He, N. An, C. Meng, L. Xiao, Q. Wei, Y. Zhou, Y. Yang, Z. Li, Z. Hu, *ACS Appl. Mater. Interfaces* **2022**, *14*(51), 57328.
86. J. Wu, L. Huang, S. Wang, X. Li, L. Wen, X. Li, T. Feng, P. Li, Z. Fang, M. Wu, W. Lv, *Energy Storage Mater.* **2023**, *57*, 549.
87. W. Lin, S. Liu, T. Gong, Q. Zhao, W. Huang, *Adv. Mater.* **2014**, *26*(4), 570.
88. Y. Li, Q. Qian, X. Zhu, Y. Li, M. Zhang, J. Li, C. Ma, H. Li, J. Lu, Q. Zhang, *InfoMat* **2020**, *2*(6), 995.
89. X. Wang, D. Hao, J. Huang, *Sci. China Mater.* **2022**, *65*, 2521.
90. C. Wang, P. Gu, B. Hu, Q. Zhang, *J. Mater. Chem. C* **2015**, *3*(39), 10055.
91. G. Li, K. Zheng, C. Wang, K. S. Leck, F. Hu, X. W. Sun, Q. Zhang, *ACS Appl. Mater. Interface* **2013**, *5*(14), 6458.
92. C. Wang, J. Wang, P. Li, J. Gao, S. Y. Tan, W. Xiong, B. Hu, P. S. Lee, Y. Zhao, Q. Zhang, *Chem. Asian J.* **2014**, *9*(3), 779.
93. X. Wang, Y. Lu, J. Zhang, S. Zhang, T. Chen, Q. Ou, J. Huang, *Small* **2021**, *17*(2), 2005491.
94. K. Xu, N. Huang, *Chem. Res. Chin. Univ.* **2022**, *38*, 339.
95. F. Niu, Z.-W. Shao, J.-L. Zhu, L.-M. Tao, Y. Ding, *J. Mater. Chem. C* **2021**, *9*(27), 8562.

96. H. Yuan, N. Li, J. Linghu, J. Dong, Y. Wang, A. Karmakar, J. Yuan, M. Li, P. J. S. Buenconsejo, G. Liu, H. Cai, S. J. Pennycook, N. Singh, D. Zhao, *ACS Sens.* **2020**, 5(5), 1474.
97. S. Jhulki, A. M. Evans, X.-L. Hao, M. W. Cooper, C. H. Ferriante, J. Leisen, H. Li, D. Lam, M. C. Hersam, S. Barlow, J.-L. Brédas, W. R. Dichtel, S. R. Marder, *J. Am. Chem. Soc.* **2020**, 142(2), 783.
98. Y. Peng, Y. Huang, Y. Zhu, B. Chen, L. Wang, Z. Lai, Z. Zhang, M. Zhao, C. Tan, N. Yang, F. Shao, Y. Han, H. Zhang, *J. Am. Chem. Soc.* **2017**, 139(25), 8698.
99. S. Halder, J. Kc, C. Chakraborty, S. Pal, *IEEE J. Sel. Top. Quantum Electron.* **2024**, 30(3), 1.
100. Q. Gu, J. Zha, C. Chen, X. Wang, W. Yao, J. Liu, F. Kang, J. Yang, Y. Y. Li, D. Lei, Z. Tang, Y. Han, C. Tan, Q. Zhang, *Adv. Mater.* **2024**, 36(17), 2306414.

AUTHOR BIOGRAPHIES



Jinghang Wu received her BS degree from the School of Material Science and Engineering, Anhui University in 2022. She is now a PhD candidate in Prof. Qichun Zhang's group, City University of Hong Kong. Her research interests include the

electrochemical synthesis and applications of two-dimensional organic conjugated materials.



Qichun Zhang started his independent career at Nanyang Technological University (NTU, Singapore) as an Assistant Professor in 2009 and was promoted to Associate Professor with tenure in 2014.

In 2020, he moved to City University of Hong Kong as a tenured full professor. He has been recognized as one of highly cited researchers (top 1%) in cross-field (2018–2021), in Materials Science (2022) and in Chemistry (2023) by Clarivate Analytics. He is a fellow of the Royal Society of Chemistry. Currently, his research focuses on carbon-rich conjugated materials and their applications. Till now, he has published >540 papers and 12 patents (H-index: 113).

How to cite this article: J. Wu, S. Zhang, Q. Gu, Q. Zhang, *FlexMat* **2024**, 1, 160. <https://doi.org/10.1002/flm2.26>