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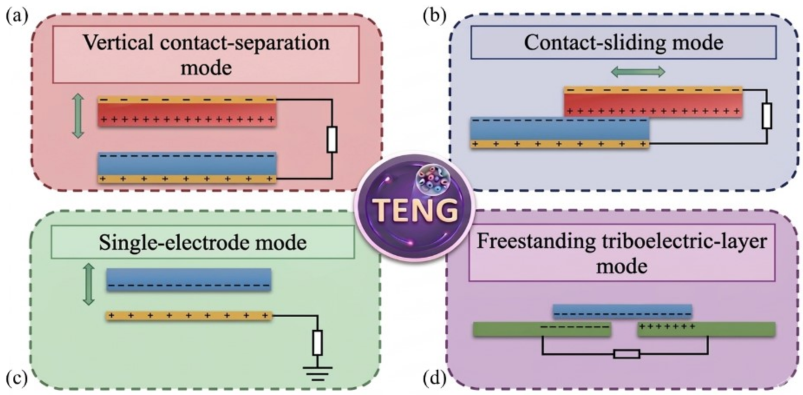

Fig.1 The four fundamental operating modes of triboelectric nanogenerators: (a) vertical contact-separation mode; (b) contact-sliding mode; (c) single-electrode mode; (d) freestanding triboelectric-layer mode.

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Triboelectric nanogenerators as self-powered active sensors

Author: Sihong Wang,Long Lin,Zhong Lin Wang
Publication: Nano Energy
Publisher: Elsevier
Date: January 2015

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Title of targeted journal	Green Chemistry
Publisher	Royal Society of Chemistry
Expected publication date	Apr 2026

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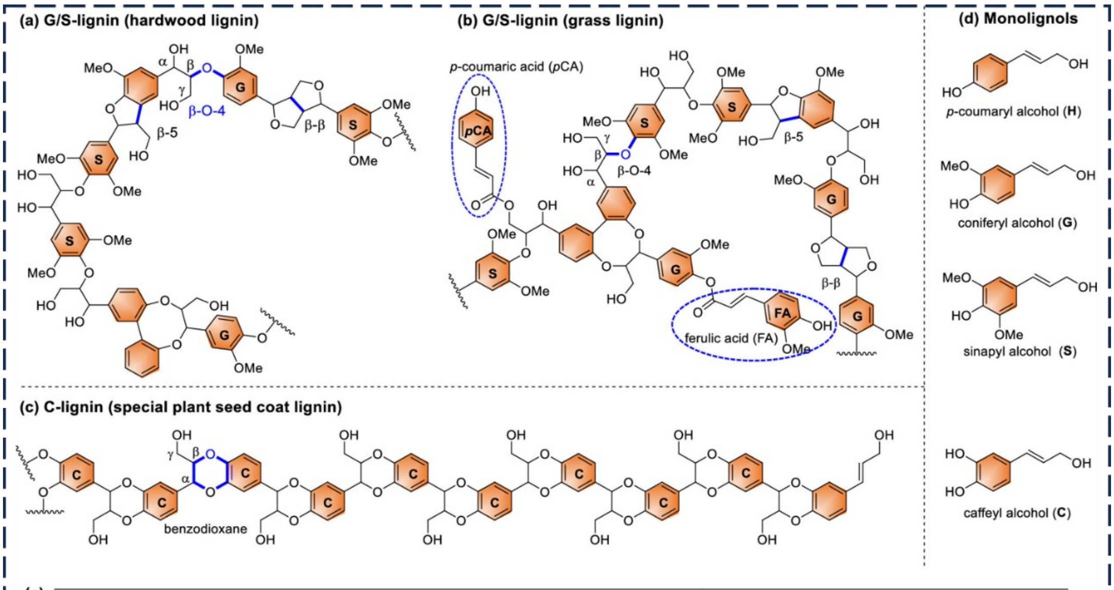

(e)

	Plants	Sununits composition (%)	Cleavage linkage proportions	Theoretical monomer yields
	hardwood	S = 46-75, G = 25-50, H < 5	50-75% (β-O-4)	40-50%
G/S-lignin	softwood	G > 95, H <5	40-50% (β-O-4)	15-25%
	grass	S = 29-61, G = 35-67, *p*CA = ~20, FA = ~10	40-50% (β-O-4)	25-35%
C-lignin	some seed coats	C = 85-100	85-98% (benzodioxane)	80-95%

Fig. 2 Representative lignin structures and typical linkage motifs: (a) G/S-type lignin from hardwood, (b) G/S-type lignin from grass, and (c) C-type lignin from certain seed coats. (d) Monomeric lignin's in different lignin samples. (e) Approximate subunit composition, linkage abundance, and theoretical monomer yield. Reproduced from Ref. [18] with permission from the American Chemical Society, copyright 2025.

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Catalytic Hydrogenolysis of Lignin into Serviceable Products

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Publication: Accounts of Chemical Research
Publisher: American Chemical Society
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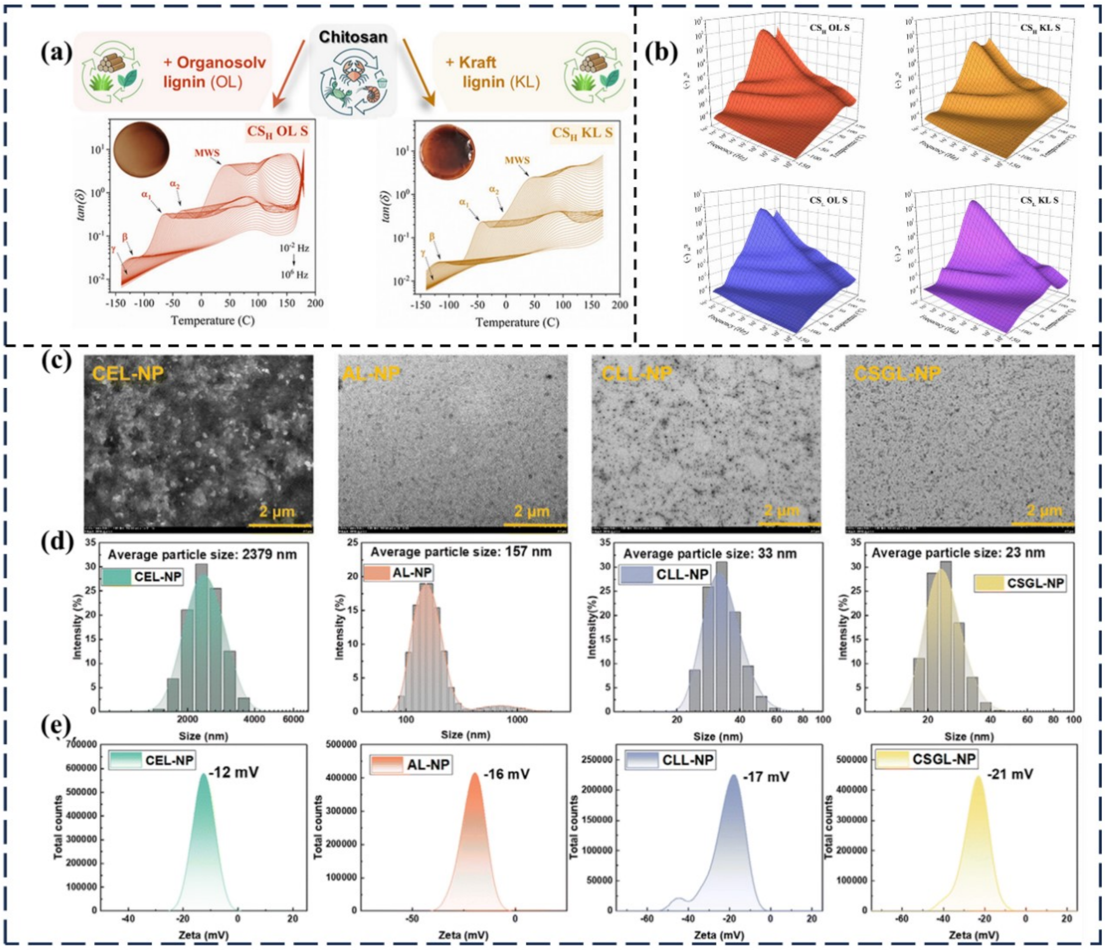

Fig. 3 (a) Isochronal plot of the dielectric loss factor tan(δ) of the protonated chitosan-lignin composites; (b) Three-dimensional plot of the imaginary permittivity (ε'') of the protonated chitosan-lignin composites; Reproduced from Ref. [32] with permission from the American Chemical Society, copyright 2025. LNPs prepared from different types of lignin (c) TEM; (d) particle size; (e) ζ-potential. Reproduced from Ref. [35] with permission from the Royal Society of Chemistry, copyright 2024.

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Fig. 3a-b

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Dielectric Characterization of Protonated Chitosan-Lignin Biocomposite Membranes: Influence of Chitosan and Lignin Types

Mark H. Wolf, Nagore Izaguirre, Jalel Labidi, and Amparo Ribes-Greus*

Open PDF Supporting Information (1)

Abstract

Biobased chitosan-lignin composite membranes with tailored dielectric and conductive properties were developed using chitosan of high (CS_H) and low (CS_L) molecular weight and degree of deacetylation, combined with kraft (KL) and organosolv lignin (OL) as fillers. The membranes were protonated by immersion in 1.0 M sulfuric acid. CS_H composites exhibit stronger ionic interactions with sulfate groups compared to CS_L composites, resulting in a dense structure that hinders water absorption and increases fragility. Chitosan interactions with sulfuric acid and lignin restrict the mobility of dielectric relaxations, with KL having a more pronounced effect than OL due to its smaller size and higher phenolic OH content. The membranes act as electrical insulators, exhibiting electron conductivities ranging from 10^{-15} to 10^{-8} S/cm between −10 and 170 °C, and proton conductivities between 2.9×10^{-3} and 4.4×10^{-3} S/cm at 60 °C. These properties make them promising candidates for use as biobased electrolytes in fuel cell applications.

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This summary highlights only some of the key features and terms of the actual

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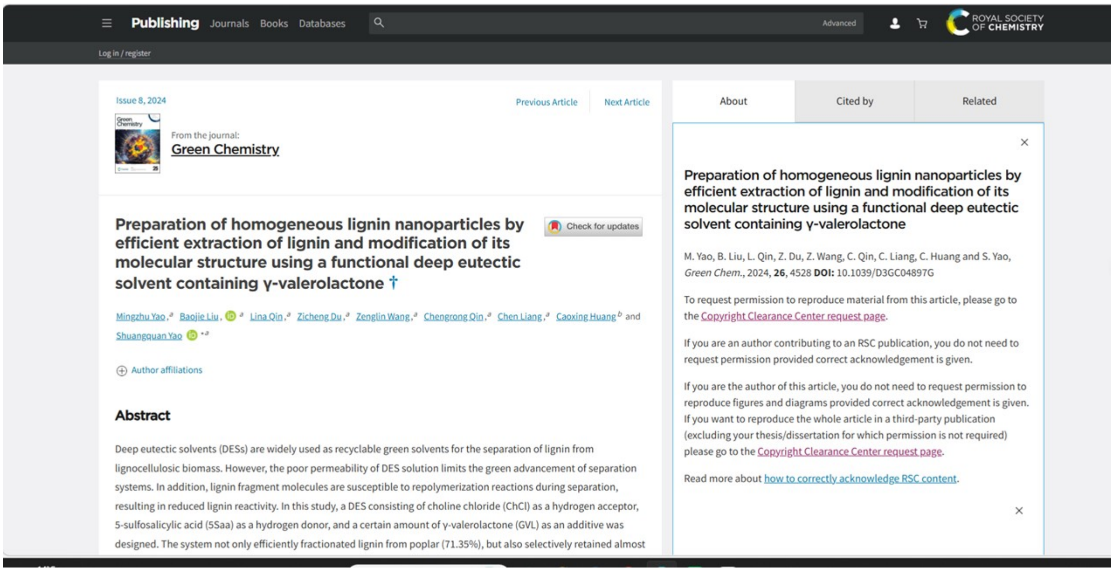
1. Introduction

The depletion and rising costs … nvironmental damage, have spurred growing interest in biobased m… es, such as chitin and lignin, provide eco-

Fig. 3c-e



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From the journal: Green Chemistry

Preparation of homogeneous lignin nanoparticles by efficient extraction of lignin and modification of its molecular structure using a functional deep eutectic solvent containing γ-valerolactone †

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Mingzhu Yao,[a] Baojie Liu,[a] Lina Qin,[a] Zicheng Du,[a] Zenglin Wang,[a] Chengrong Qin,[a] Chen Liang,[a] Caoxing Huang[b] and Shuangquan Yao*[a]

Author affiliations

Abstract

Deep eutectic solvents (DESs) are widely used as recyclable green solvents for the separation of lignin from lignocellulosic biomass. However, the poor permeability of DES solution limits the green advancement of separation systems. In addition, lignin fragment molecules are susceptible to repolymerization reactions during separation, resulting in reduced lignin reactivity. In this study, a DES consisting of choline chloride (ChCl) as a hydrogen acceptor, 5-sulfosalicylic acid (5Saa) as a hydrogen donor, and a certain amount of γ-valerolactone (GVL) as an additive was designed. The system not only efficiently fractionated lignin from poplar (71.35%), but also selectively retained almost

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Preparation of homogeneous lignin nanoparticles by efficient extraction of lignin and modification of its molecular structure using a functional deep eutectic solvent containing γ-valerolactone

M. Yao, B. Liu, L. Qin, Z. Du, Z. Wang, C. Qin, C. Liang, C. Huang and S. Yao, *Green Chem.*, 2024, **26**, 4528 **DOI:** 10.1039/D3GC04897G

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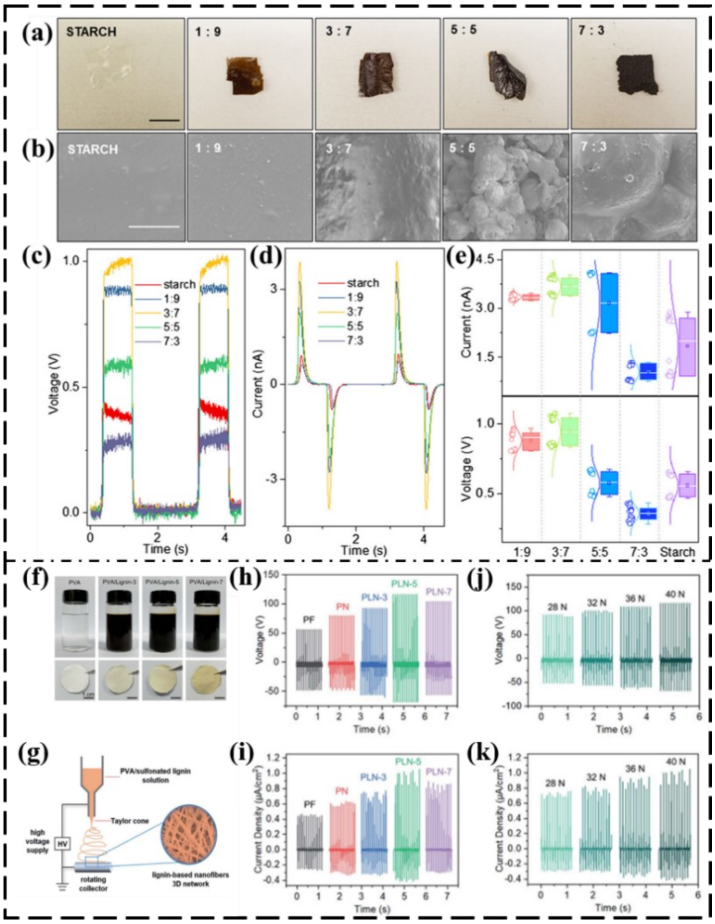

Fig. 4 Lignin-starch nanocomposite TENG. (a) Optical images of the lignin-starch films composed of different concentrations of lignin. Scale bar: 3.5 cm. (b) Scanning electron microscope images of the lignin-starch films showing the various surface morphologies. Scale bar: 100 μm. (c) Open-circuit voltages and (d) short-circuit current of the lignin-starch films. (e) Statistical results of the TENG outputs for each film. Reproduced from Ref. [37] with permission from the American Institute of Physics, copyright 2017. (f) Photographs of PVA solution, PVA/lignin solutions with lignin concentrations of 30%, 50%, and 70%, and their corresponding electrospun nanofibers; (g) Schematic illustration of the preparation process for lignin-based electrospun nanofibers; Output voltage (h) and current density (i) of TENGs based on PVA film (PF), PVA nanofibers (PN), and PVA/lignin composite electrospun nanofibers (PLN) measured at 40 N and 10 Hz; Output voltage (j) and current density (k) of the PLN-5 TENG under different applied forces at a constant frequency of 10 Hz. Reproduced from Ref. [59] with permission from the Royal Society of Chemistry, copyright 2022.

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Fig. 4a-e

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Lignin biopolymer based triboelectric nanogenerators

Author: Bao, Yukai; Wang, Ruoxing
Publication: APL Materials
Publisher: AIP Publishing
Date: May 31, 2017

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Fig. 4f-k

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From the journal:
Sustainable Energy & Fuels

Sustainable lignin-based electrospun nanofibers for enhanced triboelectric nanogenerators †

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Junya Wang, ‡ [a] Yanglei Chen, ‡ [a] Yanglei Xu, [a] Jiahui Mu, [a] Junying Li, [a] Shuangxi Nie, [b] Sheng Chen *[ab] and Feng Xu *[a]

Author affiliations

Abstract

Recently, sustainable triboelectric nanogenerators (TENGs) based on biodegradable biomaterials have attracted tremendous attention to efficiently harvest mechanical energy in a cost-effective and environmentally friendly strategy. Lignin, as the second most abundant biopolymer on earth, however, requires further development for TENGs with improved power generation. Herein, we have fabricated sustainable hybrid lignin-based nanofibers (LNFs) *via* electrospinning and prepared LNF-based TENGs. By adjusting the lignin content in the composite nanofibers, we achieved the tuning of LNFs' microstructure and tribo-polarity. The obtained TENGs are endowed with enhanced output performance due to the strong tribo-positivity of lignin and the high specific surface area of the 3D-network LNFs. The optimized output is realized after the trade-off between improved tribo-positivity and formed beads that

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Sustainable lignin-based electrospun nanofibers for enhanced triboelectric nanogenerators

J. Wang, Y. Chen, Y. Xu, J. Mu, J. Li, S. Nie, S. Chen and F. Xu, *Sustainable Energy Fuels*, 2022, **6**, 1974 **DOI:** 10.1039/D1SE02005F

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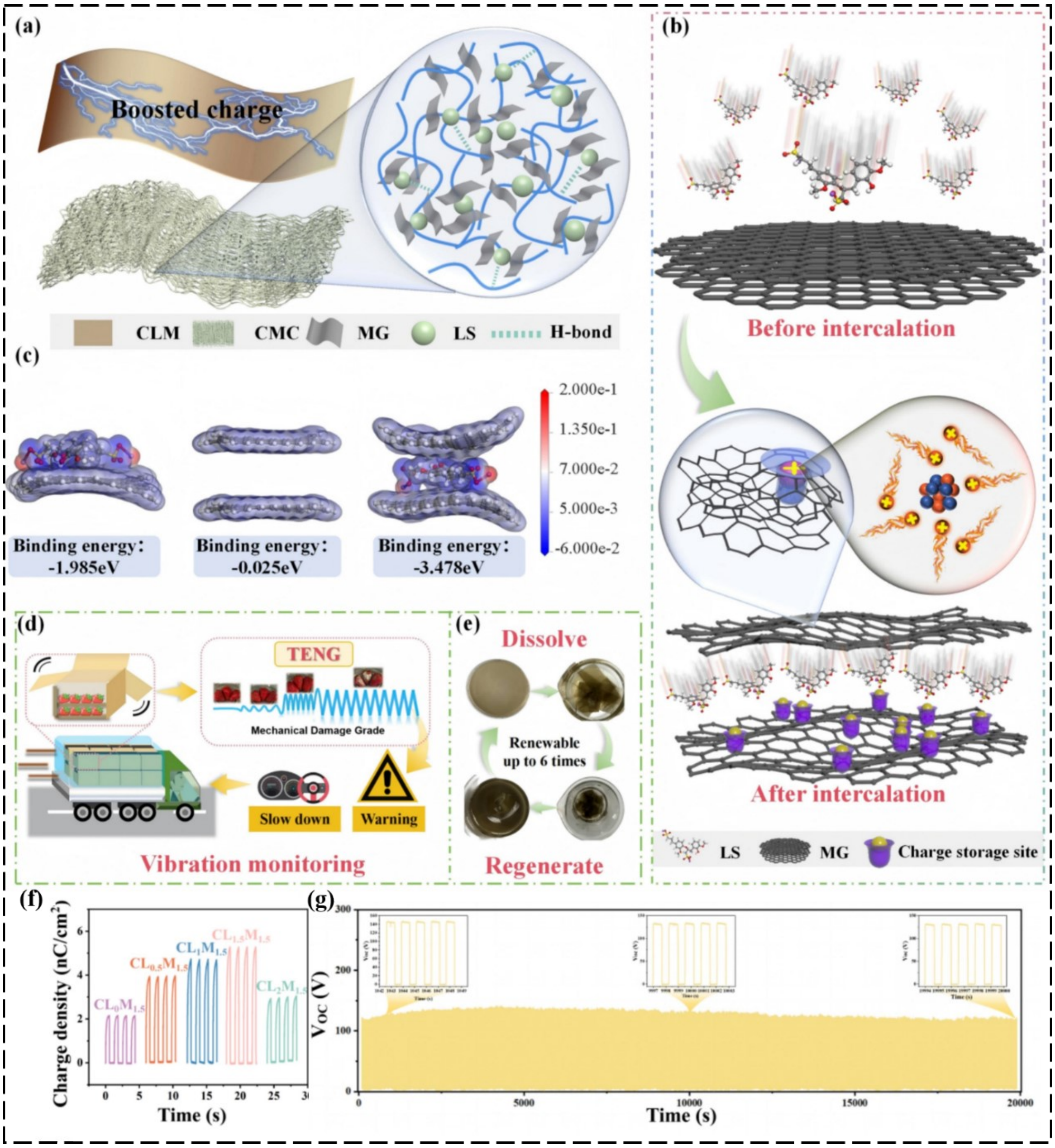

Fig.5 (a) Schematic diagram of contact electrification between carboxymethyl cellulose/sodium lignosulfonate/multilayer graphene (CLM) and PVDF; (b) Intercalation effect of LS within MG; (c) Binding energy between MG and LS calculated via DFT; (d) Potential application of the CLM-TENG in monitoring impact conditions during fruit transportation; (e) Reusability of the CLM composite; (f) Charge density of the CLM-TENG; (g) Long-term stability of the $CL_{1.5}M_{1.5}$-TENG over 40,000 cycles in ambient atmosphere.

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Inserting sodium lignosulfonate into multilayer graphene in boosting the interfacial polarization of triboelectric nanogenerators for monitoring the impact state of fruits

Author: Meiyi Chen,Xin Li,Tianshuang Bao,Cheng Cai,Yehan Tao,Jie Lu,Chenglong Fu,Jinwen Hu,Jun Xie,Xiaodong Xia,Xuejiao Wang,Jian Du,Haisong Wang

Publication: Chemical Engineering Journal

Publisher: Elsevier

Date: 15 October 2025

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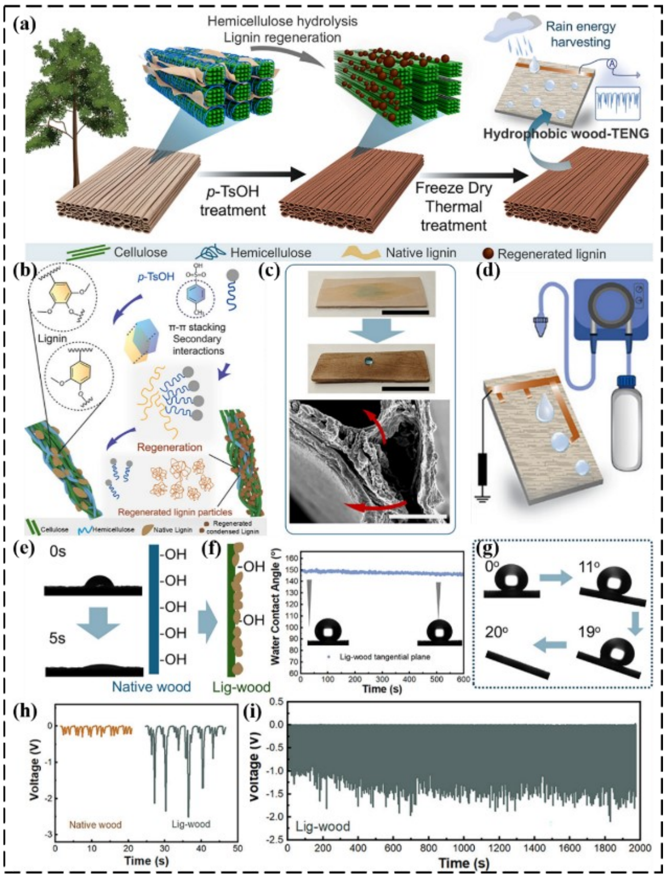

Fig. 6 (a) Schematic diagram of the process for converting wood into a superhydrophobic TENGs material; (b) Schematic illustrating the structural and morphological changes of lignin during the wood treatment process; (c) Photographs of unmodified wood and lignin-modified wood after dyed water droplet deposition (scale bar = 2 cm). A SEM image is included, revealing the microstructure of the cross-section of the lignin-wood and indicating the formation of spherical lignin particles (scale bar = 200 µm). (d) Schematic of the assembled liquid–solid (L-S) TENG in single-electrode mode; (e) Static water contact angle measured on unmodified wood over 5 seconds and a schematic of its surface properties; (f) Surface changes of the native lignin (Lig-wood) and its static water contact angle on the tangential plane (measured over 600 s, with WCA images shown at 10 s and 500 s); (g) Rolling water contact angle of the Lig-wood; (h) Voltage output generated by unmodified wood and Lig-wood; (i) Cyclic voltage output of a water droplet continuously falling onto the Lig-wood for 2000 s.

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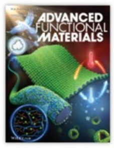

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Native Lignin Migration and Clustering in Wood: Superhydrophobic, Antimold, and Tribonegative Layers for Rain-Driven Electrification

Xuetong Shi, Ran Bi, Xin Shu, Peipei Wang, Yeedo Chun, Zhixiang Chen, Chris Zhou, Yi Lu, Orlando J. Rojas

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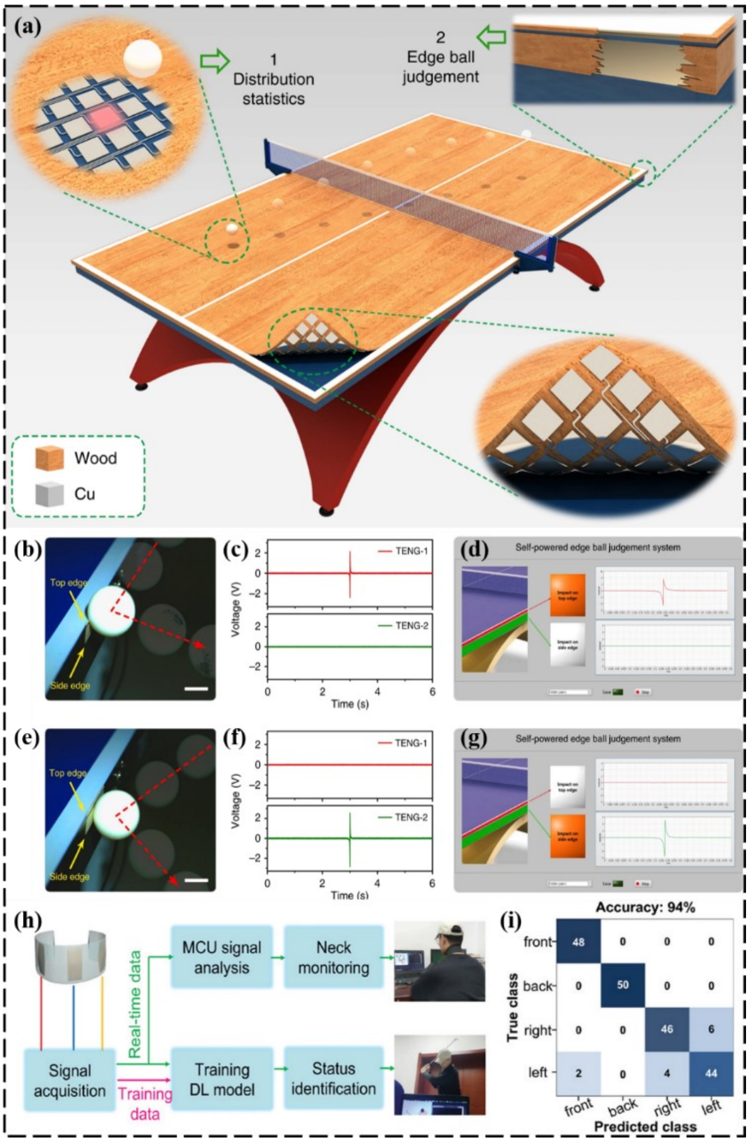

Fig. 7 (a) Schematic diagram of a natural wood-based intelligent table tennis table. Demonstration of the self-powered edge ball judgment system when the ball hits the table's top edge: (b) photograph, (c) output signals from the two W-TENGs, and (d) screenshot of the real-time judgment result displaying "Ball hits the table's top edge". Scale bar: 2 cm. Demonstration of the self-powered system when the ball hits the table's side edge: (e) photograph, (f) output signals from the two W-TENGs, and (g) screenshot of the real-time judgment result displaying "Ball hits the table's side edge". Scale bar: 2 cm. Reproduced from Ref. [113] with permission from the Springer Nature, copyright 2019. (h) Workflow diagram of the intelligent behavior monitoring system. (i) Confusion matrix for the recognition of four different neck movement states, achieving a recognition accuracy of 94%. Reproduced from Ref. [114] with permission from the Wiley, copyright 2023.

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Fig. 7a-g

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Flexible and durable wood-based triboelectric nanogenerators for self-powered sensing in athletic big data analytics

Author: Jianjun Luo et al
Publication: Nature Communications
Publisher: Springer Nature
Date: Nov 26, 2019

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Fig. 7h-i

Deep - Learning - Assisted Neck Motion Monitoring System Self - Powered Through Biodegradable Triboelectric Sensors

Author: Fengxin Sun, Yongsheng Zhu, Changjun Jia, et al
Publication: Advanced Functional Materials
Publisher: John Wiley and Sons
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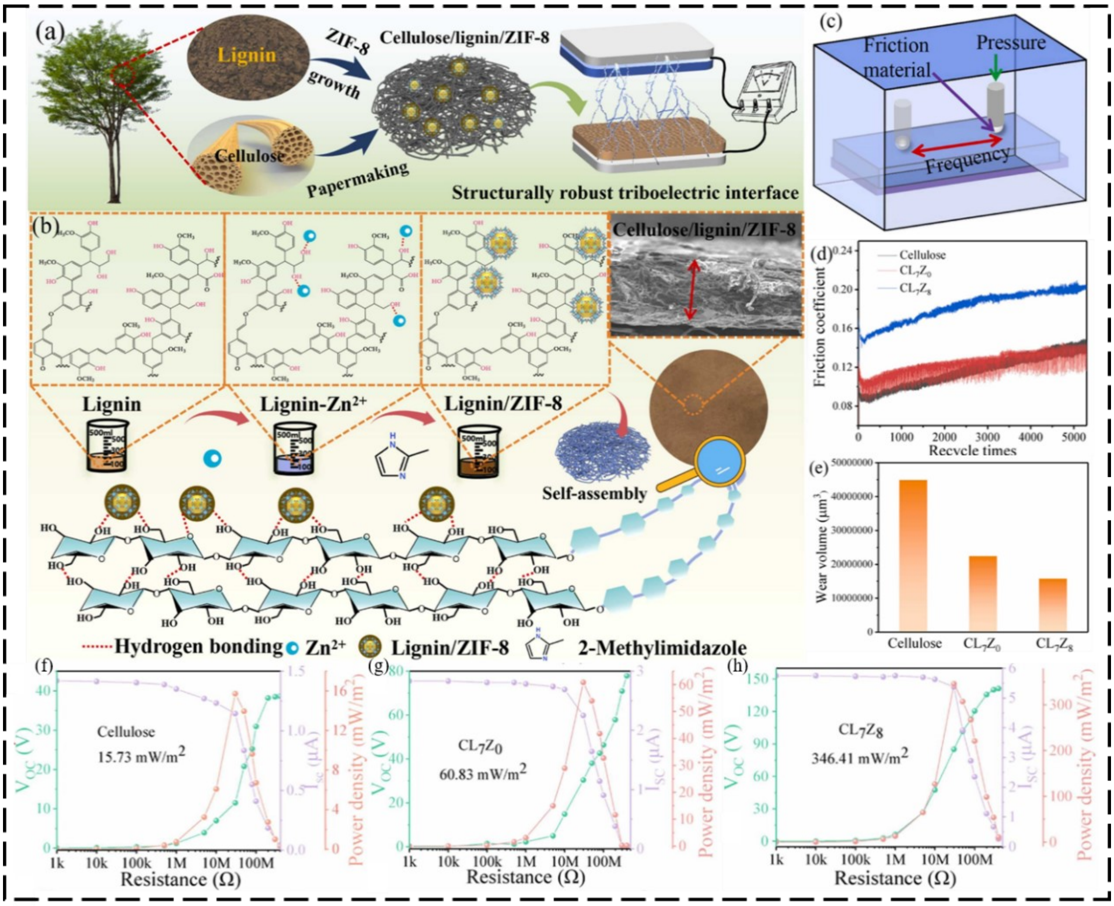

Fig. 8 (a) Schematic diagram illustrating the fabrication of wear-resistant cellulose-based triboelectric materials; (b) Detailed evolution process of the interactions involved; (c) Schematic of the tribological testing setup under 3 N and 3 Hz; (d) Coefficient of friction; (e) Wear volume; Output power density of (f) pristine cellulose, (g) CL_7Z_0, and (h) CL_7Z_8. Reproduced from Ref. [31] with permission from the Elsevier, copyright 2025.

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Wear-resistant cellulosic triboelectric material for robust human-machine interface and high-performance self-powered sensing

Author: Chao Li,Liucheng Wang,Chenglong Fu,Jiaji Yue,Yehan Tao,Jinwen Hu,Dong Lv,Haisong Wang,Daoai Wang,Jian Du
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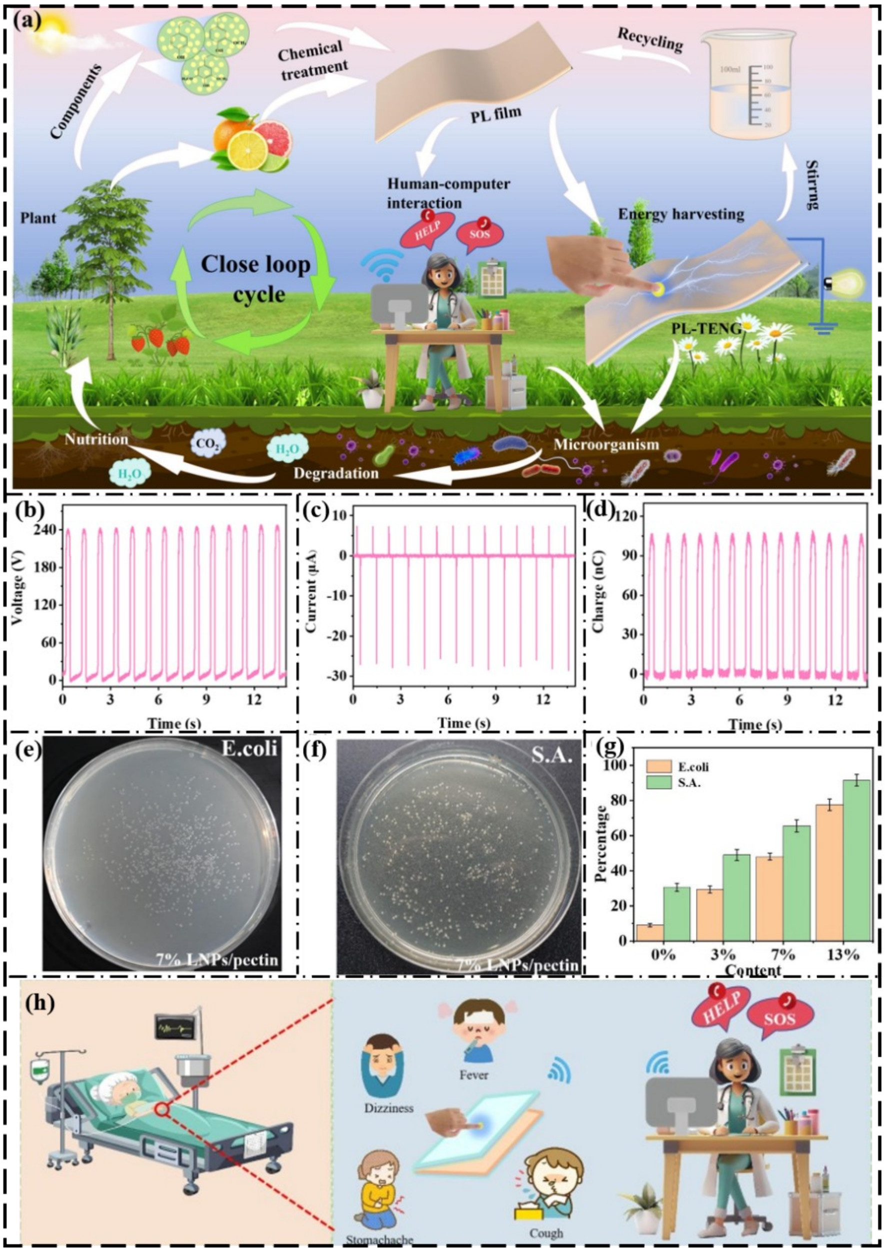

Fig. 9 (a) Schematic illustration of the biodegradability and recyclability of the PL film and the PL-TENG. (b) Open-circuit voltage (Voc), (c) short-circuit current (Isc), and (d) transferred charge of the PL-TENG measured at an operating frequency of 1 Hz. Antibacterial effects of the 7% LNP/pectin film against (e) E. coli and (f) S. aureus. (g) Comparison of bacterial inhibition rates for pectin films with different LNP contents. (h) Schematic illustrating the interaction between a patient and a doctor via a wearable PL film-based TENG sensor. Reproduced from Ref. [142] with permission from the Elsevier, copyright 2025.

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Triboelectric materials with UV protection, anti-bacterial activity, and green closed-loop recycling for medical monitoring

Author: Jiandan Liang,Qiuxiang Yang,Ce Zhang,Wen Jiang,Shounian Cheng,Yang Tao,Lin Peng,Yu Han,Xia Cao,Zhong Lin Wang
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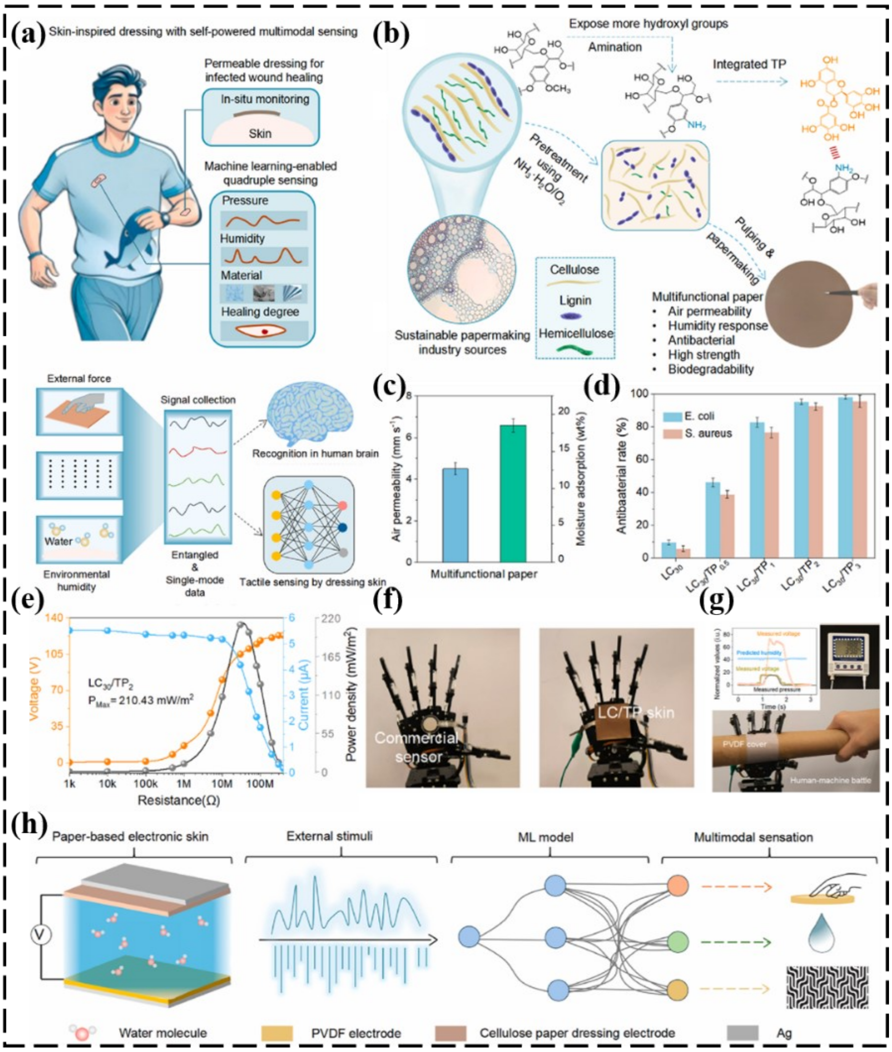

Fig. 10 (a) Schematic diagram of the lignocellulose paper-based dressing, which promotes human skin healing and enables self-powered quadruple sensing. (b) Illustration of the fabrication process of the lignocellulose paper dressing and the amination of lignin during the pretreatment. (c) Air permeability and moisture absorption of the LC_{30}/TP_2 composite paper. (d) Antibacterial rate of the lignocellulose paper dressing as a function of TP doping content. (e) Calculated output power density of the LC_{30}/TP_2-based triboelectric nanogenerator. (f) Sensor assembly on a robotic hand and a photograph of a human-robot competition. (g) Synchronous monitoring of material type, pressure, and humidity using the LC/TP TENG. (h) Schematic diagram illustrating the simultaneous monitoring of pressure, humidity, and material type based on a well-designed machine learning model.

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Natural lignocellulose fibers-based bio-dressing for accelerated wound healing and machine learning-assisted smart multimodal sensing

Author: Chao Li,Jian Du,Lingyu Zhu,Jinwen Hu,Chenglong Fu,Jie Lu,Haishun Du,Haisong Wang,Dong Lv

Publication: Biomaterials

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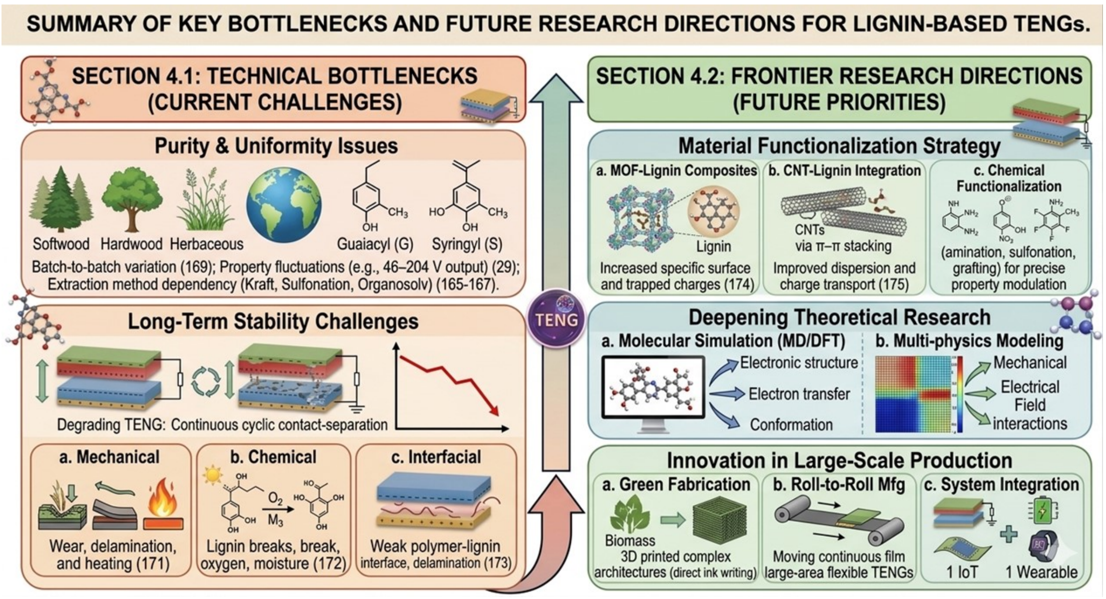

Fig. 11 Schematic overview of current technical bottlenecks and future research directions for lignin-based triboelectric nanogenerators. The left panel summarizes the key challenges in material uniformity and long-term stability, including source-dependent structural variations, batch-to-batch fluctuations, and mechanical, chemical, and interfacial degradation mechanisms. The right panel illustrates the three main future research directions: material functionalization (MOF composites, CNT integration, and chemical modification), theoretical deepening (molecular simulation and multi-physics modeling), and scalable manufacturing (3D printing, roll-to-roll processing, and system integration). Relevant references are indicated in parentheses.