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SPECIAL ISSUE Flexible, Stretchable and Printable Electronic Materials for Sustainable Healthcare, Sensing and Actuation, Energy Applications and Interconnections

GUEST EDITORIAL

Flexible, Stretchable, and Printable Electronic Materials for Sustainable Healthcare, Sensing, Actuation, Energy Applications, and Interconnections

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1 | Introduction

Electronic systems are moving beyond the planar, rigid, and brittle architectures that have historically dominated the field toward devices that are soft, conformable, lightweight, and mechanically resilient under repeated deformation. This transition is driven by rapid advances in flexible, stretchable, and printable electronic materials and their processing. Conductive, semiconducting, and dielectric systems that combine high functional performance with the mechanical compliance of soft matter are emerging. Such materials encompass a broad and rapidly expanding materials landscape, ranging from carbon- and metal-filled polymer nanocomposites, MXenes, conductive hydrogels, and intrinsically stretchable polymers to liquid metals, organic semiconducting gels, and bioinspired interfaces for intimate coupling with biological and environmental surfaces.

A central scientific challenge in this field is to establish robust process- structure- property relationships that link material composition, microstructure, interfacial architecture, and processing history to electrical, mechanical, and electromechanical performance. Maintaining a high conductivity, charge transport, dielectric integrity, and device functionality under large strain, cyclic loading, bending, twisting, and environmental exposure remains a critical requirement for real-world deployment. When coupled with scalable manufacturing approaches such as inkjet printing, aerosol-jet printing, screen printing, blade coating, and additive manufacturing, these materials enable device architectures that are inaccessible to conventional rigid electronics. Representative application areas include skin-mounted systems for continuous physiological monitoring, soft sensors conforming to plant and biological tissues, deformable human-machine interfaces, and self-powered energy-harvesting platforms integrated into textiles, objects, and soft robotic systems.

Progress in this rapidly evolving area requires more than incremental advances within isolated disciplines. Meaningful breakthroughs depend on the integration of materials design, ink formulation, advanced processing, multiscale characterization, mechanical and electrical reliability testing, and device-level validation. This interdisciplinary framework provides the scientific foundation for both Symposium G "Flexible, stretchable and printable electronic materials for sustainable healthcare, sensing and actuation, energy applications and interconnections" at the European Materials Research Society 2025 Spring Meeting and this Special Issue, which together highlight recent developments in soft, stretchable, and printable electronic materials and their translation into functional devices.

Tobias Kraus, Wim Deferme, Esther García-Tuñón, Jang-Ung Park, Monika Rai, and Shweta Agarwala contributed equally to this work.

2 | Special Issue Information

This Special Issue of *Advanced Materials Technologies* grew out of Symposium G, "Flexible, Stretchable and Printable Electronic Materials for Sustainable Healthcare, Sensing and Actuation, Energy Applications and Interconnections," held at the E-MRS 2025 Spring Meeting in Strasbourg, France, organized by Monika Rai, Tobias Kraus, Wim Deferme, Esther García-Tuñón, Jang-Ung Park, and Shweta Agarwala. The Special Issue comprises 21 manuscripts, including 19 research articles, 1 review, and 1 perspective article. The work focuses on the latest advances from fundamental materials properties to applied device concepts, organized across four thematic areas: Materials Design and Functional Systems; Processing and Advanced Manufacturing; Characterization and Reliability; and Devices and Applications. This collection highlights the multidisciplinary nature of the field and provides a platform to showcase the current state of the art while identifying future directions. We sincerely thank Jolke Perelaer for his dedication and support in assembling this collection. Below, we briefly highlight the contributions through the lens of each thematic area.

2.1 | Materials Design and Functional Systems

The foundation of any flexible or stretchable electronic system lies in the design of its constituent materials–conductors, dielectrics, and active components that must simultaneously meet demanding electrical and mechanical specifications. The contributions in this section address novel functional materials strategies, spanning stimuli-responsive polysiloxanes, textile-integrated graphene composites, soft electrofluids, and multimodal haptic interfaces.

Opris and co-workers demonstrate light-switchable ionic conductivity in arylazopyrazole-modified polysiloxanes, offering new possibilities for stimuli-responsive electronic materials (admt.202501850). Salim and co-workers investigate smart textile materials by studying the sensing behavior of glass fabrics coated with waterborne polyurethane/graphene dispersions for sustainable sensing applications (admt.202502030). Quinn and co-workers develop flexible chemiresistive chitosan-glycerol sensors on laser-induced graphene electrodes for room-temperature ammonia detection (admt.202502109). González-García and co-workers investigate the influence of morphology on the electromechanical performance of graphene-based electrofluids for emerging soft electronic systems (admt.202502646). Bardea and Patolsky report a multimodal haptic perception through a synergistic polydimethylsiloxane and multiwall carbon nanotubes doped with nickel nanoparticles, integrated into a vertical-via wearable architecture (admt.202600010).

2.2 | Processing and Advanced Manufacturing

Realizing flexible and stretchable electronic systems at scale demands manufacturing strategies that are simultaneously versatile, precise, and compatible with functional material inks and substrates. The contributions in this section encompass ultrasonic spray coating, binder-jet and extrusion-based 3D printing, laser-based direct writing, and liquid-metal patterning–collectively advancing what can be fabricated on flexible and unconventional substrates.

Deferme and co-workers investigate droplet formation mechanisms in ultrasonic spray coating using Phase Doppler Anemometry (PDA) combined with machine learning, providing new insights into ink formulation effects for scalable coating processes (admt.202502104). Rane and co-workers further explore additive manufacturing by demonstrating binder-jet 3D printed ceramic substrates designed for high-frequency 5G patch antenna applications (admt.202502039). Lopez and co-workers report the laser printing of thermoelectric materials on flexible substrates and employ machine learning approaches to optimize device performance (admt.202502634). Magdassi and co-workers present the 3D printing of porous conductive polyurethane structures that are stretchable and compressible, enabling new opportunities for soft robotics (admt.202502588). Rai and coworkers address fabrication challenges in liquid-metal direct writing, proposing strategies to overcome printing and interfacial limitations for integrated stretchable electronics (admt.202502023). Shanumgam and co-workers use the additive manufacturing approach to engineer a three-dimensional printed microarchitected hierarchically porous biodegradable PLA/S/CNT nanocomposite electrode for high-performance Lithium-Sulfur batteries (admt.202600003). Albert and co-workers present an alternative approach through graphene-in-ink formulation in inkjet-printed $MAPbBr_3$ for enhanced photodetection (admt.202600007). Samuel and co-workers use predictive master curves for high-quality Direct Ink Writing (DIW) of Anisole Inks (admt71226).

2.3 | Characterization and Reliability

Translating flexible electronic materials from laboratory demonstrations to reliable devices requires a thorough understanding of their structure-property relationships and failure mechanisms. The contributions in this section apply advanced characterization methodologies–from fatigue testing of liquid-metal interconnects to nanoscale force microscopy of perovskite photodetectors–to reveal the fundamental factors governing performance and durability.

Rai and co-workers analyze mechanical fatigue in liquid-metal interconnects, providing detailed insights into failure mechanisms and validating strategies to improve device durability (admt.202502172). Narayan and co-workers, in their review article, highlight the essential functionalities required for hydrogel-based electrolytes for structurally resilient flexible supercapacitors (admt.202502636). Ciavatti and co-workers use advanced Kelvin probe force microscopy, correlative x-ray fluorescence and x-ray beam-induced current nano-mapping to establish that grain boundaries are functional photoactive elements, providing a clear design strategy for optimizing 2D perovskite photodetectors (admt.202600004).

2.4 | Devices and Applications

The ultimate test of any new material lies in the performance of the systems built from it. The contributions in this section span a wide application landscape–from self-powered energy harvesting and wound care management to electrochemical biosensing, agricultural monitoring, and next-generation injectable neural probes–demonstrating the broad societal impact that flexible and stretchable electronics can deliver.

Das and co-workers develop a La-$YFeO_3$ perovskite/PVDF-HFP composite triboelectric nanogenerator designed as a self-powered insole energy harvester (admt.202501962). Zhang and co-workers report a stretchable smart dressing for burn wound management that enables efficient exudate collection and strain-insensitive monitoring at joint sites (admt.202502012). Kumar and co-workers demonstrate flexible Au-modified $MoSe_2$ nanowhiskers as a high-performance electrochemical platform for non-enzymatic dopamine detection (admt.202502108). Defer me and co-workers present a liquid-metal-based stretchable strain sensor for monitoring fruit growth in agricultural applications (admt.202502435). Finally, Jiwon Kim and Tae-il Kim provide a perspective on the development of next-generation injectable probes inspired by the historical evolution of catheter technologies (admt.202502199).

3 | Conclusion

We are grateful to all authors, reviewers, and the editorial team of *Advanced Materials Technologies* for their contributions and support for this Special Issue. We hope this collection will serve as a valuable reference for the community, highlighting both the exciting opportunities and the open challenges that remain for flexible, stretchable, and printable electronic materials and their real-world applications.

Conflicts of Interest

The authors declare no conflicts of interest.